University of Alberta

Forages and Tannin Supplementation for White-Tailed Deer

by

©

Grant Allan Chapman

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Abstract

Three studies in northern Alberta, Canada, determined if white-tailed deer (WTD) exhibited seasonal compensatory growth and evaluated the effects of Spruce and Quebracho tannin (QT) supplemented diets on white-tailed deer (WTD) performance. Suitability of Alfalfa, Birdsfoot Trefoil, Chicory and Alsike Clover perennial forages and Berseem Clover, Canola, Pea, and Turnip annual forages was also evaluated. Alfalfa suitability was reaffirmed with preference (utilization and grazing time) and weight gains greater in chicory and trefoil. Establishment, productivity, and seasonal biomass and quality of all forages were good with winterkill severe in trefoil and chicory. Annual forages quality was excellent with WTD highly selective preferring peas and berseem with nutrient yield highest in turnips. WTD regulated intake of QT, selecting 3-3.4% QT in diets, causing reduced weight gain and feed intake and had no effect fecal parasite loads. QT diets (6-15%) reduced protein digestibility, feed intake, weight gain, and the urine urea:creatinine ratio.

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Dedication

I dedicate this thesis to the management and conservation of all wildlife, to the role that land owners play as stewards of their habitat, and to the Quality Deer Management Association for promoting our common passion of White-tailed Deer management.

I also dedicate this to my parents, Mark and Terry Chapman, and family, for the endless love, support, encouragement, and their belief in my ability.

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List of Abbreviations

ADF	Acid Detergent Fiber
CP	Crude Protein
CT	Condensed Tannin
DM	Dry Matter
DMI	Dry Matter Feed Intake
NDF	Neutral Detergent Fiber
MBW	Metabolic Body Weight
QT	Quebracho Tannin
RPI	Relative Preference Index
ST	Spruce Tannin
U:C	Urea to Creatinine
WTD	White-tailed Deer
Digest.	Digestibility

1.0. Introduction

White-tailed deer (*Odocoileus virginianus*) (WTD) are native to North America and highly adaptable with a distribution ranging from South America to the Northwest Territories of Canada. Interest in deer farming worldwide for high quality antler velvet, venison products, and recent demand for quality WTD trophy hunting opportunities has resulted in a keen interest in their production in North America (Telfer and Scotter, 1975; Alsager and Alsager, 1984; Twiss et al., 1996). Also fueling this increase was an interest in native ungulate production that more efficiently utilized pastures in Alberta. This led to the Livestock Industry Diversification Act and Regulations in 1991 which limits game farming in Alberta to WTD, mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*) and moose (*Alces alces*).

The Canadian farmed deer population in 2001 was 53 258 deer comprising fallow deer (*Dama dama*), WTD, mule deer, and red deer (*Cervus elaphus*) (Statistics Canada 2001). Prior to 2001, the farmed deer population has rapidly increased in Alberta, doubling from 1996-2001 (Statistics Canada 2002). As of 2006, deer numbers in Canada had declined slightly to 46 748, and within the provinces of Alberta and Saskatchewan there were 17 546 deer on 238 farms, comprised primarily of WTD, and to a much lesser extent, fallow and mule deer (Statistics Canada 2006). Declines in farmed deer numbers have been attributed to breeding animal market stabilization and chronic wasting disease concerns when in September of 1998 a moratorium was established on importing deer and resulted in border closures and translocation restrictions nationwide. All provinces now require some form of Cervid Chronic Wasting Disease Surveillance and Herd Certification Program with movement of animals controlled by the Canadian Food Inspection Agency.

The WTD is North America's most sought after big game animal with many hunters pursing them for their trophy antlers. Alberta and Saskatchewan WTD have long been known for their large antlers, with Saskatchewan home to the World Record WTD Along with wild deer outfitting, the provinces of

Saskatchewan and Quebec permit the hunting of game-farmed deer on Cervid Harvesting Preserves. Saskatchewan's high fence trophy hunting ability is the major driving market that is sustaining the WTD industry in western Canada. Within the U.S. the whitetail industry is rapidly growing with record-setting prices being offered for trophy breeding animals (Bloomington Illinois Whitetail Extravaganza 2006), Alberta's industry is suffering as it has a difficult time meeting translocation requirements to market animals to Saskatchewan and the United States. A trophy whitetail hunt costs on average about $ 4500.00. As the Canadian industry has slowed in development, the American deer farming industry now far surpasses it in trophy quality and availability which further reduces the price for Canadian trophy deer. Recently, the low relative value of the American dollar places more stress on the Canadian hunting outfitting market. Many farmed WTD never reach trophy quality for hunting with some farmers choosing to market the remaining animals for venison.

Venison markets are driven by consumers becoming more health conscious; therefore, game meats are an attractive choice as they are leaner and lower in calories, fat and cholesterol than traditional red meats (Cordain et al., 2002). The European Union and Japan are the major global consumers of these meat products, and tend to import large quantities from all parts of the world. Although Canada now has numerous internationally approved slaughter facilities they contribute very little on a global scale as whitetails have high production and slaughter costs relative to carcass size and value and that greatly reduces profit margins; furthermore this market has not been fully developed.

Production cost of rearing whitetails is high due to fencing and nutritional requirements. WTD do not make efficient use of grass pastures (Hans-Joachim 1997) and therefore depend heavily on year-round supplemental feeding with concentrates, a more expensive feeding alternative than provision of pasture (Delaby et al., 2001; Beever and Doyle, 2007). Reducing production costs through more sustainable feeding systems has been identified as a priority (Arriaga-Jordán et al., 2001; Alberta Agriculture 2003) Feed costs comprise the majority of production costs for ruminant livestock and thus it become focal areas for improvement efforts. The deer industry needs suitable pastures and low-cost supplements for critical seasons when pastures decline in quality. Recent research has identified condensed tannin supplementation as a possible means of increasing the production efficiency in deer (Barry and Manley 1986; Hudson et al., 2000) through improved protein utilization (Makkar et al., 1995) and anthelmintic effects (Nguyen et al., 2005).

Condensed tannins are polyphenolic compounds of high enough molecular weight to bind with proteins and are plant chemical anti-herbivory defenses (Bate-Smith and Swain, 1962; Bryant et al., 1992). Whitetail deer have evolved consuming tannin-enriched diets and have developed mechanisms to reduce the negative effects associated with tannin consumption and may benefit from their consumption (Robbins et al 1987a; Hudson et al., 2000).

Now that price has stabilized, the WTD industry must direct attention to production costs and development of more economically and environmentally-sustainable systems based on strategic feeding and husbandry programs. This applied research study evaluated new low-cost feeding strategies. It aims to apply emerging knowledge of the role of plant secondary compounds, specifically condensed tannins, in ruminant nutrition while providing new insights into non-conventional ruminant livestock nutrition by evaluating their adaptations and production responses to various dietary components. It also evaluates the suitability of alternative perennial and annual pastures forages, some containing tannins, in Northern Alberta, Canada.

1.1. Classification

White-tailed deer belong to the Cetartiodactyla Order, the Ruminantia Suborder, the family Cervidae, and Subfamily Odocoileinae which includes two North American species, *Odocoileus hemionus*, and *Odocoileus virginianus* (Hall, 1981; Smithsonian, 1993; Wilson and Reeder 2005) with the status of some of the most atypical genera within this classification not well established (Fernandez and Vrba, 2005). It was originally documented in 1780 by Zimmermann (Smith 1991) and now has 38 recognized subspecies widely distributed from South America to the Northwest Territories of Canada (Halls 1984).

1.2. Distribution and Habitat

In Alberta, two subspecies are present, *Odocoileus virginianus dacotensis*, the Dakota WTD and *Odocoileus virginianus onchrourus*, the Northwest WTD (Alberta Environmental Protection Natural Resource Service 1995). Population levels of WTD have increased in the last century due to lack of competition from elk and bison, warmer winters, reduced hunting pressure, increases in agricultural land conversion, fire and predator suppression (Todd and Geisbrecht 1979), with highest densities found in the prairie river bottoms, aspen parkland, and boreal mixed wood forest fringe eco regions (Alberta Environmental Protection and Natural Resource Service (AEPNRS) 1995). The preferred habitats include those areas with $\geq$65 hectares of continuous woody cover within 1.6 km from an equivalent area, as they provide protection from disturbance, security from predators, accessible escape cover, a high diversity of browse and forbs species, and landscape and vegetation features necessary for energy conservation and thermal regulation during critical cool and warm periods (AEPNRS 1995). Quality of habitat also typically increases with proximity to lands having agriculture crops and those that have reduced snow accumulation.

1.3. Description

The Dakota WTD has the largest body and antler size of the subspecies with males reaching 130 kg and in some rare instances 160kg (AEPNRS 1995). The pelage is reddish brown in spring and summer and turns a grey brown throughout the fall and winter (Klein 1999); earning their common name by their habit of raising their long white (underside) conspicuous tail, when alarmed. WTD antlers are prized by sportsman with male deer antlers beginning development at 4 months of age, and after 1 year and older, , increase in size with body weight, nutrition (Harmel, 1982), age, and genetics (Smith et al. 1982). Ullery, (1983) identified energy, protein, phosphorous, calcium, and vitamins A and D as being the most important nutritional factors affecting antler growth with energy and protein deficiencies decreasing antler volume, diameter, number of points, and beam length. Antler growth begins in mid April to early May, with velvet stripped in September, and antlers shed mid March

(Jacobson and Griffin 1982). The presence of antlers is a distinguishing characteristic of the cervidae family. Antlers are bony, non-keratinous complex structures, consisting of a long, multi-branched distal element attached to a short non-deciduous pedicle or base (Miyamoto et al., 1990) arising from the frontal bones (Bubenik 1982). Breeding activity peaks near the end of November and gestation lasts and average of 195-202 days with females averaging 2 fawns. Sexual maturity can be reached by the first fall and is primarily a function of body weight with 53% of female fawns breeding in measured populations of CFB-Wainwright (Hall 1973).

1.4. Digestive Physiology

Deer are considered ruminants as they regurgitate ingesta from the reticulum, followed by remastication and reswallowing. It provides for effective mechanical breakdown of roughage and there by increases substrate surface area (Hofmann 1989) while minimizing feeding time and predation risk (Bergman et al. 2001; Kie 1999). They have a four compartment stomach including the rumen, reticulum, omasum, and abomasum and have symbiotic relationships with anaerobic microbes to digest their food (Van Soest, 1994; Hungate 1985).

Fermentative bacteria provide a comprehensive battery of digestive capabilities and are often classified by their substrate preferences which include cellulolytic (digest cellulose), hemicellulolytic (digest hemicellulose), amylolytic (digest starch), proteolytic (digest proteins), sugar utilizing (utilize monosaccharides and disaccharides), acid utilizing (utilize such substrates as lactic, succinic and malic acids), ammonia producers, vitamin synthesizers, and methane producers (Bowen 2007b). Hofmann (1989) extensively reviewed the morphophysiological history of ruminant animals placing all ruminant species within a flexible system of 3 overlapping feeding types. For the majority, selectivity is the key factor in several strategies of adaptation to changing forage quality and availability. The three categories are: (1) Grazers: roughage feeders that select mostly grasses and sedges; (2) Browsers: concentrate selectors that feed mostly on forbs, fruits, nuts, leaves, twigs, and bark of trees and shrubs; (3) Mixed Feeders: intermediate feeder between grazer and browser - adapted to grazing grasses, forbs, and woody plants (Hofmann

1989). This categorization of ruminant feeding types has been seriously challenged (Robbins et al. 1995); however an extensive review of the literature and subsequent study (Clauss and Lechner-Doll 2001) supports the classification put forth by Hofmann (1989).

WTD are considered browsers who possess many specialized physiologic adaptations ensuring efficient utilization of their dietary niche. The prehensile organs involving lips, curved incisor bar, long muzzle, and relatively large space between the incisors, and the low-crowned molars, facilitate highly selective foraging (Church 1979; Haigh and Hudson 1993; Gordon and Illius 1998). Browsers are best adapted to forage with rapid initial fermentation but low asymptotic digestibility, skimming readily digestible nutrients and propelling refractory particles rapidly through the digestive tract, extracting fewer nutrients from feed compared to mixed feeders and grazers (Chaplin 1987; Klein 1999). Lundberg and Palo (1993) suggested two different ways in which herbivores can cope with low-quality browse diets; individuals can either increase retention time of forage in the rumen to maximize nutrient extraction or accelerate passage to extract easily digested components allowing high voluntary intake of forages. Browsers represent the latter, and relative to grazers, lack in their ability to selectively restrict passage of rumen contents by particle size (Clauss and Lechner-Doll 2001) due to differences in rumen content stratification (Renecker and Hudson 1990); grazers stratify rumen contents quite well and results in a more complete fiber digestion.

The WTD gut is small relative to body weight and the rumino-reticulum is small relative to the total digestive tract (Klein 1999). Compared to grazers, browsers have a relatively small and simplified rumen which is not capable of digesting large quantities of feed high in cellulose (Hans-Joachim 1997). However, browser rumen pappillae development is greater relative to grazers and stimulated by the presence of volatile fatty acids (Hofmann 1979). As peripheral blood flow in the rumen papillae is reduced, cornification increases and thus the papillary surface enlargement becomes reduced, a cyclic physiological process adapted to environmental seasonal feed constraints (Hofmann 1979). WTD average 10-12 feeding bouts/day and cattle (grazer) 3-4 bouts/day (Klein 1999).

Browsers possess salivary glands up to 4 times larger than grazers (Robins et al. 1995) capable of producing high volumes serous, proline rich saliva, with a high tannin binding capability (Austin et al., 1989), important as plants browsed by deer may contain up to 20% condensed tannin (Hudson et al. 2000). Saliva further acts to buffer rising rumen pH from excessive volatile fatty acid production, maintains high flow rates of digesta to the omasum, preventing rumen distension, allowing increased forage intake.

WTD possess a high degree of rumen motility, retaining the ability to bypass the rumino-reticulum through a highly developed reticular groove, permitting passage of the bolus directly to the omasmal orfice, preventing microbial breakdown of high quality foods (Hofmann 1973). This results in a higher efficiency of utilization and protection of feedstuffs which can be critical in conserving limiting proteins which is common in ruminant diets (Orskov 1986).

The omasum of some browsers has a large orifice and fewer laminar folds which allow larger particles to pass maintaining high passage rates (Hofmann 1979). The low pH of the abomasum ensures microbial killing and thorough digestion of the neutral detergent soluble and easily digestible cellular components including: fructans, glucans, pectic substances, sugars, starches, organic acids, protein, fatty acids, pigments, waxes, and soluble phenolics (Ball et al., 2001; Chalupa and Sniffen 2007). Dietary energy (1-Neutral Detergent Fiber (including cellulose, lignin, fiber-bound and heat-bound nitrogen, and hemi-cellulose) comes from these soluble and digestible fibers (mainly hemicelluloses) (Robbins and Moen, 1975; Ball et al., 2001).

WTD also possess an enlarged caecum (Hofmann, 1985) which enables them to post-ruminally further microbially digest forages releasing nutrients similar to hind gut fermentors, an ability that strict cranial fermentors cannot benefit from. This ability, in conjunction with reticulo-rumen bypassing, increases nutrient conversion efficiency assuming components necessary for proper microbial growth are not limiting. Sheep were found to gain a 17% increase in cellulose digestion (Gray 1946) in their ceacum with mean retention times found to be twice (7 hours) that of red deer (3.4 hours) on ad libitum grass diets (Milne et al., 1978). Hofmann (1979) summarizes the digestive morphophysiological adaptations of a browser/concentrate selector in relation to other ruminants.

1.5. Seasonal Adaptations

WTD are adapted to survive highly seasonal and extreme environments as evidenced by their distribution (Smithsonian 1993). One very significant adaptation of cervids is a well-developed seasonality of metabolic and productive functions where cycles appear strongest among deer at higher latitudes and elevations with tropical deer being considered non-seasonal (Long et al. 1965; Silver et al., 1969; Ozoga and Verme 1970; Mautz 1978; Moen, 1978; Verme 1988; Worden and Pekins 1995; Hudson 2007). Seasonal metabolic requirements are a function of activity level, thermoregulation requirements, forage type, and dry matter intake, and are closely linked to hormone levels, controlled by photoperiod (Hudson 1987; Dumont et al. 2005; Hudson 2007;), an example of such a cycle is the lipogenic cycle where it was found that WTD fawns artificially exposed to extended photoperiod accumulated 47% less abdominal fat (Verme 1988). This annual cycle is vital to northern WTD as up to 30% of the energy necessary to survive over winter can come from body reserves (fat and protein) (Mautz, 1978) which determines how long they survive under a negative energy budget (Oristland, 1977). Thus, food represents the main source of energy for ungulates during the dormant season (Mautz, 1978).

WTD do not always meet their energy requirements from ingestion of woody browse as forage digestibility is typically low and in some years, winter starvation can kill over 40% of individuals (Dumont et al. 2005). During harsh winters WTD tend to decrease their selectivity, while increasing bite size, and reducing movements (Dumont et al. 2005) foraging by energy maximizing and time minimizing in early and late winter respectively (Schmitz 1991). Locomotion costs increase exponentially with snow sinking depth (Parker et al., 1984), with reductions in activity related to the decline in forage quality and availability, increase of snow cover, and colder daily temperatures (Beier and McCullough 1990; Jiang and Hudson, 1994). Deer foraging on prostrate plants becomes limiting and WTD begin switching to a browse diet when snow depths reach 7.6 cm (Telfer 1978) and begins to immobilize deer at depths greater than 50-60cm.

A multitude of factors influence forage intake in ruminants including digestibility, rate of passage through the gastrointestinal tract, local climatic conditions, forage quality, and forage availability (Welch and Hooper 1993). Many ungulates modify their foraging behavior in winter, reducing activity and voluntary forage intake, to conserve energy expenditures and minimize body mass loss (Short et al., 1975; Taillon et al. 2006). Accordingly, ungulates may decrease energy expenditure in winter and summer, maintaining within their thermo neutral zones (Schmitz 1991) by modifying their activity rate, concentrating their active bouts during the warmer daylight hours, and foraging in habitats with little snow (Beier and McCullough 1990). The main determinant of over winter survival in WTD fawns was body mass in early winter (Dumont et al. 2005). Another important body mass is birth weight as it effects future growth and body mass up to 2.5 years later in WTD and is a reflection of body condition of pregnant does (Schultz and Johnson 1995).

Gestation in WTD increases metabolism on day 91 of gestation of pregnant deer and rises curvilinear with 92.2% of the increase occurring in the third trimester (Pekins et al. 1998). Costs were 45% greater in the last trimester for pregnant than for non-pregnant WTD, peaking at 200 days gestation and requiring 617 kJ/kg Metabolic body weight per day (MBW); 84% above that of non-pregnant deer resulting in a 16.4% gestation term increase in forage requirements. The temporal increase in energy costs was correlated with spring green-up, indicating important relationships between energy demands, food quality and availability, spring weather, and physiological adaptations in deer (Pekins et al. 1998).

Elk exhibit a strong compensatory growth effect during this green-up where by lighter animals gain more rapidly than heavier, better conditioned animals (Hudson 2007), with seasonal appetites in WTD ranging from 1.4 times or 50%-60% greater in spring and summer as compared to winter, synchronizing seasonal metabolic and reproductive functions with forage supplies (Haigh and Hudson 1993). This project will investigate whether a similar compensatory growth relationship occurs in WTD.

1.6. Diet, Forage Selection, and Preferences

WTD select only the most nutritious, rapidly digestible plant species and parts rather than an average of all the forage available (Klein 1999). Recent studies have indicated the importance of browse, forbs, and grasses in the diets of WTD (Allen 1968; Coblentz 1970; Segelquist *et al.* 1972; Sotala and Kirkpatrick 1973; McCaffery *et al.* 1974). A review and comprehensive evaluation of western Canadian winter browse diets was recently conducted (Racz, Christensen and Feist 1999). It was found that Hazel (*Corlyus cornuta*), Trembling Aspen (*Populus tremuloides*), Balsam Poplar (*Populus balsamifera*), Cranberry (*Vaccinium sp.*), Willows (*Salix sp.*), Saskatoon (*Amelanchier alnifolia*), Chokecherry (*Prunus virginiana*), Buffalo berry (*Shepherdia canadensis*), Juniper (*Juniperus sp.*), Red Osier Dogwood (*Cornus stolonifera*), Rose (*Rosa sp.*), Wolf Willow (*Eleagnus commutata*), and White Birch (*Betula papyrifera*) were the most important browse species and *Lathyrus sp*, and *Medicago sativa*, and *Aster sp*., the most important forbs species, with alfalfa equaling use of all other forbs where available (Telfer and Scotter 1975; Racz, Christensen and Feist 1999). Other important agricultural winter forages include, annual cereal crops. Winter rumen contents in CFB-Wainwright were found to contain 60% browse, 26% forbs, 6% grass, and 8% unidentifiable matter (Rhude and Hall 1977). WTD prefer current annual growth as it is less lignified, with winter browse generally lower in digestible components, proteins, starches, sugars and hemi-cellulose (Hans-Joachim 1997; Racz, Christensen and Feist 1999). Initial spring diets have a high proportion of grass species as cellulose contents at this time of year are low (Wishart 1984) and account for up to 13% of the annual diet (SRNF 2007). The most preferred group of forages for WTD is forbs, with many factors affecting their utilization.

Central to the study of animal ecology is the usage an animal makes of its environment, specifically, the kinds of foods it consumes and the variety of habitats it occupies. Many analytical procedures have been devised to treat data on the usage of such resources, particularly in relation to information on their availability to the animal, for the purpose of determining "preference" (Johnson 1980). Forage preferences occur when a plant is proportionately more frequent in the diet than the available environment (Petrides 1975; Heady 1964), the primary value being to rank various plants with regard to their palatability under a specified set of conditions (Kreuger 1972).

Numerous preference indices exist involving: a numbered ranking (Johnson 1980), coefficient of preference ratio centered on unity (Ndikumana and De Leeuw 1996; Bork pers. com. 2007), and palatability rating (Bartlett 1958), and numerous forms of relative preference indices (Van Dyne and Heady 1965; Chamraq and Box, 1968). Most indices are based on usage, availability, and the frequency that the plants occur in the diet and encompass both utilization and observation estimates by means of measuring time spent foraging, bite rate, bite size, forage removal, degree of utilization and by examining fecal, rumen, and esophageal fistula samples among others (Heady 1964). Heady (1964) extensively reviewed and Krueger (1972) and Am. Soc. Range Mgmt., (1962) have reviwed and compared preference indices. Holochek et al., (1982) reviews methods for determining botanical composition in ruminant diets including the methods of diet observation, utilization techniques, fistula sampling, and fecal analysis. Hull et al. (1960), further discusses observational studies of grazing animals.

Preference can vary greatly and is affected by landscape, plant, animal modifying factors and the interactions among them (Johnson 1980; Krueger 1972; Heady 1964, Cowlishaw and Alder 1960). Landscape properties include soil type and fertility, soil moisture, light availability, proximity to fecal material, proximity to the animal, topography and availability (Cowlishaw and Alder 1960; Heady 1964; Krueger 1972; Owen-Smith and Cooper 1987). Animal properties include life stage; nutritional requirements, learned behavior, evolution of food habits, and post-ingestive feedback, gut fill (Heady 1964; Cowlishaw and Alder 1960; Provenza et al., 1992), and can vary between individuals (Arnold and Drawe 1979). Plant properties include spines, thorns (Cooper and Owen-Smith 1986) odors, moisture content, growth stage of the whole plant and its leaves, previous defoliation history, cultivar, species, season of use, plant community structure, nutrients, secondary metabolites, and chemical make up (Heady 1964; Cowlishaw and Alder 1960; Owen-Smith and Cooper 1987) (discussed further in later sections of this literature review).

Palatability is defined as plant characteristics or conditions which stimulate a selective response by grazing animals (Heady 1964), which drives preference, and degree of utilization (Ball et al. 2001). Factors determining palatability include texture, leafiness, fertilization, moisture content, and presence of compounds that cause forages to taste sweet, sour, salty, or cause an astringent flavor with highly palatable plants indicative of high quality forages (Ball et al. 2001). Forage quality can be defined as the extent to which forage has the potential to produce a desired animal response (Ball et al. 2001). It can be indirectly measured using analyses providing estimates of protein, energy, fiber, contents and digestibility's as well as animal response measures including fiber, milk, meat, antler, velvet production and weight gain. As forage qualities vary on both temporal and spatial scales, along with forage requirements of the animal (Table 4.6 Nutritional requirements of WTD), so too does the preference for that particular forage. Plants have evolved many mechanisms which reduce their palatability and subsequent preference and fitness.

1.7. Herbivory Deterring Mechanisms

Plants invest significant amounts of resources to deter defoliation by spatially limiting availability (Cooper and Owen-smith 1986), physical mechanisms, (Milton 1991, Owen-Smith and Cooper 1987) and chemical mechanisms (Bryant et al., 1992). Selection for anti-herbivore defenses in plants may be related to the life form of a plant, the fauna with which a plant evolves and abiotic factors that determine the rate at which plants grow (Milton, 1991). Plant chemical and physical attributes are closely linked with environmental variables (Campbell and Werger, 1988) and soil fertility (Coley 1987;Milton, 1991). Presumably, chemical composition is the most important palatability factor (Heady 1964). Some plant secondary compounds that deter foraging include: esters, flavanoids, alkaloids, saponins, sequiterpines, nitrates, cyanoglycosides, estrogens, mycotoxins, and polyphenols (Rhoades and Cates 1976; Bryant et al 1992). Of particular interest to this study is the group of polyphenolic compounds generally referred to as tannins.

Tannins are a diverse group of polyphenolic, water -soluble compounds that precipitate proteins and other macromolecules and are part of a diverse group of polyphenols that are formed as secondary metabolites in plants (Bate-Smith and Swain, 1962; Bryant et al., 1992). Tannins comprise a wide range of oligomeric and polymeric polyphenols; proanthocyanidins, gallotannins, and ellagitannins (Khanbabaee and van Ree, 2001; Deaville et al., 2007). The gallotannins and ellagitannins are also known as hydrolyzable tannins and the proanthocyanidins known as condensed tannins. (Khanbabaee and van Ree, 2001; Deaville et al., 2007). They are typically found in cell walls or within vacuoles in stems, bark, leaves, flowers, or seeds, and mainly in dicotyledonous plants (Barry 1989).

Hydrolysable tannins are hydrolyzed by weak acids or weak bases to produce carbohydrates and phenolic acids and are subsequently absorbed and can cause severe necrosis and ulceration of the epithelium and the esophagous, stomach, intestines and renal tubes (Mcleod 1974, Divers et al., 1982). Proanthocyanidins are more commonly known as condensed tannins (CT) due to their condensed structure and are polymers of flavanoid units that are joined by carbon-carbon bonds which are not susceptible to being split by hydrolysis and are not absorbed and thus their effects can be less severe (Cornell University 2001).

The ability of tannins to form strong complexes with proteins is the most important aspect of their nutritional and toxicological effects (Hagerman and Butler, 1981). The strength of these complexes depends on characteristics of both tannin and protein (molecular weight, tertiary structure, isoelectric point, and compatibility of binding sites) which affect their reactivity thereby browsing (Clausen et al., 1990) and differs between species of plants (Makkar and Becker 1998; Barry and Mcnabb, 1999; Min et al., 2003; Rautio et al., 2007). Responses to CT consumption are both herbivore-specific and concentration-dependant with tannin tolerance decreasing among ruminant species in the order: deer>goat>sheep>cattle (Kumar and Singh 1984; Robbins et al., 1987[a]; Robbins et al. 1987[b]). Deer possess adaptations to counter the negative effects of tannin consumption including the production of protein-rich saliva which bind tannins during mastication, (Provenza and Malachek 1984; Robbins et al 1987a) and reduce their protein-binding ability (Provenza and Malachek 1984; Robbins et al 1987a)

Ruminants generally select against tannins in natural forages containing above 5% CT (Cooper and Owen-Smith, 1985; Cooper et al., 1988; Distel and Provenza, 1991; McArthur et al., 1993). CT concentrations in the range of 2-4% are generally accepted to provide some optimal benefits (Barry, 1983; Barry and Manley 1986; Schreurs et al., 2002) with regulation of their intake associated with aversion learning theory (Provenza, 1995; Provenza et al., 2000) in ruminants.

Benefits of CT supplementation at low concentrations are linked to increasing by pass protein and net absorption of amino acids, adjustment of the protein:energy ratio, leading to more efficient digestion and decreased ammonia production (Makkar et al., 1995). As protein is often limiting in ruminant diets this ensures that protein conversion efficiency is maximized, important as the protein:energy ratio has a large effect ruminant performance (Perdok et al. 1988). CT may reduce ammonia production in the rumen and subsequent urea losses, reduces protozoan populations, and protects protein from bacterial digestion. Other known benefits of tannin supplementation include an anthelmintic effect on gastrointestal parasites (Hoskin et al., 2000; Nguyen et al., 2005).

Tannin chemical defenses deter herbivory by astringency (Kumar and Singh, 1984), toxicity and CT above 5% can become an anti-nutritional factors in plant material fed to ruminants (McLeod, 1974) having an adverse effect on feed intake (Marten and Ehle, 1984; Palo, 1985; Salunkhe et al., 1990; Waghorn et al., 1990; Barry and McNabb, 1999; Windham et al., 1990) and rumen function (Barry, 1983; Barry, 1985; Norton and Ahn, 1997;) reducing digestibility of fiber in the rumen (Reed et al. 1985) by inhibiting the activity of bacteria (Chesson et al. 1982) and anaerobic fungi (Akin and Rigsby, 1985) and complexing with proteins (Van Sumere et al. 1975), cellulose, pectin, starch, and alkaloids (Swain 1965; Haslam 1979) and by blocking digestive enzymes and interfering with protein activity in the gut wall (Van Soest 1982). Undigested feed accumulates in the rumen as a result of the inhibitory effects of condensed tannins on microbial fermentation, reducing feed intake and passage rates (Waghorn et al., 1990).

High levels of CTmay become lethal to an animal that has no other feed (Kumar, 1983) with tannin poisoning reported in cattle consuming *Quercus* species (Garg et al., 1992). Tannins inhibit nutrient utilization increasing the costs of ingesting toxins (Robbins et al., 1987a,b, 1991) with detoxification of metabolized and absorbed toxins requiring nutrients such as energy, protein, and water (Illius and Jessop, 1995) that otherwise would be available for maintenance and production (Freeland and Janzen, 1974; Illius and Jessop, 1995). Adverse effects of tannin ingestion are learned and remembered through instantaneous and post-digestive feedback mechanisms (Bryant et al., 1992; Provenza et al., 1992). Very little is known about CT consumption by WTD (Hudson et al., 2000) and is of particular interest to this study as they show potential in reducing costs of feeding through increased feed efficiency.

1.8. Feeding Systems

A limiting factor in ruminant production systems is the high cost (40-67%) of feeding, which represents most of the production costs; due to the high use of commercial concentrates (USDA, 1995; Arriaga-Jordan et al., 2002; Beever and Doyle 2007; Nayigihugu et al., 2007). Development of more efficient feeding systems has become a priority (Arriaga-Jordan et al., 2001) and production costs can be reduced through a larger reliance on home-grown high-quality forages (Delaby et al., 2001; Beever and Doyle, 2007). It has been shown that swath grazing is less labor intense (McCartney et al. 2004) and is more cost effective than a bale feeding strategy (Volesky et al. 2002) due eliminating the costs of baling, transporting, and feeding forage with similar cost reductions experienced when using perennial grazed forages vs. provision of cut annual forages. Although costs are reduced, profitability of some of these systems varies with farm operation (Beever and Doyle, 2007). Feeding efficiency is an effective measure of evaluating profitability of farm productivity.

Recently, Min et al., (2003), Racz et al., (1999), GAPT (199) and Ramirez-Restrepo and Barry (2005) reviewed diets, and currently used and alternative forages for deer production. Alfalfa is benchmark pasture legume species well adapted to growth in Alberta. Alfalfa has beneficial yield and quality attributes, grazing tolerance, along with consistent performance across grazing management systems and environments with many varieties available to suit forage production needs (Smith et al., 2000). Hudson et al., (1993) evaluated its potential use in cervid diets. One potential drawback of its use is that it contains sapponins which may limit rumen motility, a critical adaptation for deer who consume browse diets (Sen et al., 1998). Tannin concentrations in alfalfa are low with tannins occurring in the seed coat (McAllister et al., 2005). These forage evaluations also identified chicory (*Chicorium intybus*) as good potential deer forage and linked benefits to reductions in parasite loads and increased preference and weight gains in deer (Kusmartono et al., 1996; Min et al., 1997; Schreurs et al., 2002), sheep (Fraser et al., 1988; Komolong et al., 1992; Scales et al., 1995;Scales 1993; Fraser and Rowarth 1996) and cattle (Barry 1998). Chicory had only been grown in one trial in Atlantic Canada prior to this study and its suitability for growth in western Canada was unknown.

Birdsfoot trefoil (*Lotus corniculatus*) has also been shown to improve performance of ruminants and shows potential for WTD pasture forage as it is high in quality and shows benefits of its moderate CT concentrations (Barry 1983; Barry 1985; Barry and Manley 1986; Barry 1989; Min et al., 2003). Birdsfoot trefoil is considered valuable forage with more than 1 million ha seeded in the United States (Beuselinck and Grant 1995), but presently is not a widely used legume in Alberta because of problems in stand persistence (Alberta Agriculture and Food 2007).

Evaluation of forage for deer pasture suitability requires an assessment of several agronomic traits including biomass production, forage quality and nutrient yield, and establishment and persistence. Pasture forages have to be both well-adapted to a region, highly productive, and cost effective. Native pastures may be cost prohibitive as the best habitat types are that of the aspen parkland which has a high fencing cost and handling issues may deter managers from fencing large enough areas to supply year round foraging. Annual forages use in pasture grazing systems is common practice throughout the world and shows potential for good deer pasture provided cellulose and neutral detergent fibers are low. Although much research has been conducted on the evaluation of annual forages for cattle production in western Canada, no research is available that evaluates their use as deer pasture forage.

1.9. Project Objectives

This study involves three separate but interrelated studies which aim to improve our current understanding of WTD nutrition. The first study involved the determination of the feeding value of condensed tannins. The first objective of this study is to evaluate the effect of two sources of condensed tannins, white spruce bark (*Picea glauca* Moench) and quebracho *(Aspidosperma quebracho-blanco)* on white-tailed deer performance. The second objective was to determine if WTD exhibit a compensatory growth pattern in the spring of the year. To accomplish these objectives a series of supplemental pasture and dry-lot feeding trials were used to answer the following key research questions:

1. Does CT supplementation of Spruce Tannin (ST) effect weight gain or fecal parasite loads in WTD grazing on summer pasture?
2. Given diet choice, do WTD voluntarily consume quebracho tannin (QT) and if so, how much do they prefer and what is the resultant effect on weight gain, feed intake, and fecal parasite loads during the winter and spring seasons?
3. What is the effect of fixed concentrations of QT (Low, Medium, and High) on weight gain, feed intake, and 2 indicators of digestive efficiency (protein and feed digestibility) and 3 indicators of nutritional status (urine urea, cortisol, and potassium concentrations)?
4. What is the annual seasonal growth pattern and corresponding appetites of WTD?
5. Does WTD body weight in early spring have an effect on compensatory rate of weight gain?

The specific objectives of the second study were:

6. Compare the establishment and over-winter survival of chicory to birdsfoot trefoil and alfalfa in two growing seasons.
7. Determine agronomic characteristics of the 3 forages including:
    a. Seasonal biomass production.
    b. Crude protein concentration and yields.

    c. Neutral detergent fiber concentrations and neutral detergent soluble yield.
    d. Condensed Tannin content

8. Determine dietary preferences of WTD for each of these 3 forages when given a choice.
9. Evaluate deer performance (i.e. weight gain) while grazing pastures, seeded to each species.

The third study within this project aimed to evaluate 4 annual forages and their suitability for deer pasture. The objectives of this project were to evaluate the biomass, crude protein and neutral detergent fiber (NDF) concentrations, as well as deer utilization ($kg \cdot ha^{-1}$ and %) and preference (frequency of deer grazing) for each of four annual forages, including forage peas (*Pisum sativum* L.), Argentine "Skyhawk" canola (*Brassica napus*, L.), "Samson" turnips (*Brassica rapa* var. *rapa*, L.) and Berseem clover (*Trifolium alexandrinum* Linn.).

This project will investigate the digestive adaptations of North American browsing ruminants and specifically the WTD digestive adaptations to condensed tannins. Secondly through the evaluation of both annual and perennial forages we will be able to identify alternative forages capable of meeting WTD nutritional needs. This information will be used to improve recommendations on feeding and farm management practices with aims of improving the health and efficiency of WTD production in North America.

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2.0 Chapter 2. Effects of Supplemental Dietary Tannins on the Performance of White-Tailed Deer

2.1. Introduction

Interest in deer farming worldwide has increased in the last 30 years due to Asian and European demand for high quality antler velvet and venison products. Recent demand for quality white-tailed deer (WTD) (*Odocoileus virginianus*), trophy hunting opportunities and to a lesser extent venison has resulted in a keen interest in their production in North America (Telfer and Scotter, 1975; Alsager and Alsager, 1984; Twiss et al., 1996).

Canadian deer production has rapidly increased at an annual rate of 44% from 1991-1999 and in 2001 there was 53 258 deer in Canada comprising fallow deer (*Dama dama*), WTD, mule deer (*Odocoileus hemionus*), and red deer(*Cervus elaphus*) (Statistics Canada 2001) As of the 2006, deer numbers in Canada had declined slightly to 46 748, and within the provinces of Alberta and Saskatchewan there were 17 546 deer on 238 farms, comprised primarily of WTD, and to a much lesser extent, fallow and mule deer (Statistics Canada 2006).

This decline can be attributed to breeding stock prices which stabilized in 2002 so the industry must now direct attention to reducing production costs as feed costs can account for 65% of livestock production expenses (Beranek, 2006). Furthermore, game farming systems in seasonal environments of Canada depend heavily of expensive supplements to meet nutritional needs and maximize deer performance and with high production and slaughter costs relative to carcass size and value; venison production offers marginal profits (Hudson et al. 2000).

An emerging knowledge of the role of plant secondary compounds, specifically condensed tannins (CT), in ruminant nutrition shows potential to reduce production costs (Barry and McNabb 1999). Tannins are a diverse group of polyphenolic water soluble compounds containing sufficient hydroxyls and homologous groups capable of binding and precipitating proteins and other macromolecules (Bate-Smith and Swain, 1962; Bryant et al., 1992). They are produced by plants and deter herbivory (Rhoades and Cates 1976). Responses to CT consumption are both herbivore-specific and concentration-dependant with tannin tolerance decreasing among ruminant species in the order: deer>goat>sheep>cattle (Kumar and Singh 1984; Robbins et al., 1987[a]; Robbins et al. 1987[b]). CT above 5% can become an anti-nutritional factors in plant material fed to ruminants (McLeod, 1974) and at higher levels (5– 9%) have an adverse effect on feed intake (Marten and Ehle, 1984) and rumen function (Barry, 1983; Barry, 1985 and Norton and Ahn, 1997) as they reduce digestibility of fiber in the rumen (Reed et al. 1985) by inhibiting the activity of bacteria (Chesson et al. 1982) and anaerobic fungi (Akin and Rigsby, 1985) and complexing with proteins (Van Sumere et al. 1975), cellulose, pectin, starch, and alkaloids (Swain 1965; Haslam 1979). High levels may become lethal to an animal that has no other feed (Kumar, 1983) with tannin poisoning reported in cattle consuming *Quercus* species (Garg et al., 1992).

At low to moderate levels CT (2-4%) improve ruminant performance (Barry and Manley 1986 and Schreurs et al., 2002). Dietary CT may prevent bloat (Jones et al., 1994; Tanner et al., 1995,), increase bypass protein and the net absorption of amino acids (Waghorn et al., 1987) and reduce dependence on anthelimintics (Aerts et al. 1999, Butter et al., 2001; Nguyen et al., 2005). CT also may improve production efficiency of lactation, wool and live weight gain in sheep (Aerts et al., 1999; Min et al., 1998), milk quality and productivity (Barry and McNabb 1999; Roy et al., 2004), meat flavor (Schreurs et al., 2004), and ovulation rate (Terrill et al., 1992; Wang et al., 1996a, 1996b). In Odocoileinae deer, Hudson et al. (2000) found that dry matter intakes increases with purified bark CT at inclusion levels up to 10% of the diet and suggested that performance may be improved in these mule deer. CT action in ruminants has been linked to increased absorption of essential amino acids in the small intestine due CT-protein pH sensitive bonding in the rumen, releasing the protein in the acidic environment of the abomasa (Robbins, 1983) . Considerable research has explored anti-nutritive effects of tannins on domestic livestock (Disler et al., 1975; Sandusky et al., 1977; Roy and Mukherji, 1979; Jones and Hunt, 1983; Panda et al., 1983; Van Hoven, 1984; Barry, 1985; Mehansho et al., 1987).

Deer possess several morphophysiological adaptations to tannin-rich diets (Hoffmann 1989) including the large salivary glands capable of producing proline rich saliva (Mehansho et al., 1987) that bind with tannins with some cervids being found to select and regulate tannin intake precisely (Tixier et al., 1997; Verheyden-Tixier and Duncan, 2000). Research on unique herbivore species adaptations to specific tannins has been primarily focused on domestic livestock with little feeding research being conducted on WTD.

The feeding value of tannins results from the sum of their effects on forage intake, digestive processes, and metabolism of the absorbed nutrients. The first objective of this study is to evaluate the effect of two sources of condensed tannins, white spruce bark (*Picea glauca* Moench) and quebracho (*Aspidosperma quebracho-blanco*) on white-tailed deer performance. The second objective was to determine if WTD exhibit a compensatory growth pattern in the spring of the year. To accomplish these objectives a series of supplemental pasture and dry-lot feeding trials were used to answer the following key research questions:

1. Does CT supplementation of Spruce Tannin (ST) effect weight gain or fecal parasite loads in deer grazing on summer pasture?
2. Given diet choice, do white-tailed deer voluntarily consume quebracho tannin (QT) and if so how much do they prefer and what is their resultant effect on weight gain, feed intake, and fecal parasite loads during the winter and spring seasons?
3. What is the effect of fixed concentrations of QT (Low, Medium, and High) on weight gain, feed intake, and 2 indicators of digestive efficiency (protein and feed digestibility) and 3 indicators of nutritional status (urine urea, cortisol, and potassium concentrations)?
4. What is the annual seasonal growth pattern and corresponding appetites of northern white-tailed?
5. Does deer body weight in early spring have an effect on compensatory rate of weight gain?

This information will be used to improve recommendations on feeding and farm management practices with aims of improving the health and efficiency of WTD production in North America.

2.2. Materials and Methods

2.2.1. Study Overview

Four feeding trials were conducted between June 2003 and July 2004, hereafter referred to as the Summer Pasture, Winter Pasture, Digestibility, and Compensatory Gain Trial. Tannins were added to a complete mixed pelleted ration of alfalfa (*Medicago sativa* L.). ST was used only in the Summer Pasture Trial with all other trials involving the use of QT. Trial sampling procedures and analysis were similar in all trials utilizing a completely randomized design with successive trial design improvements being made to increase power of analysis and reduce sources of error. Trial lengths ranged from 17-83 days during which measures of performance were collected on a total of 108 WTD. Tables 2.1 and 2.2 summarize the key characteristics of each trial, while detailed descriptions of the design, sampling, and statistical analysis for each trial are provided below.

2.2.2. Site Description

This research was conducted at the Alberta Best Deer Group Ltd. game farm in the Lower Boreal Mixedwood region of north central Alberta, 11 km east of the town of Athabasca (54° 42' 8.7"N; 113° 05'31.7"W). The farm consists of two quarter sections (512 ha) of land, fenced and cross fenced with 2.43m tall high tensile page wire. The farm was equipped with a large, well-designed handling and urine collection facility including many indoor and outdoor dry lot pens and pastures.

Prior to this research trial, the farm was utilized for white-tailed deer pasture and hay production, typically with forage stands consisting of alfalfa, smooth brome (*Bromus inermis* Leyess), quackgrass (*Agropyron repens* L.), and alsike clover (*Trifolium hybridum* L.). The predominant soil type on the farm was an Orthic Gray Luvisol of the La Corey, Plamondon and Spedden series (Alberta Soil Information Center 2001) on medium-textured loam and clay loam till, with poorly drained Organic soils in lowlands. The farm's deer herd consisted of all ages of bucks and does, with the herd numbering about 800 deer that are used for trophy antler, fine venison, and urine hunting scent products.

2.2.3. Subjects

Research procedures were approved by the Faculty Animal Policy and Welfare Committee following Canadian Council on Animal Care (CCAC) Guidelines. In the first three trials, hereafter referred to as the Summer Pasture, Winter Pasture, and Digestibility trials, deer were randomly selected from the 2003 male yearling buck population to minimize variation in initial body weights. To eliminate the possibility of previous exposure to tannins quebracho tannins, only 2-4 year old animals were used in the final Compensatory Gain trial. All deer were randomly selected and assigned to treatments.

2.2.4. Evaluation of Spruce Tannin Supplements on Pasture during the Summer Pasture Trial

Spruce bark is a potential local source of CT's and were used in this trial as Hudson et al. (2000) found that *Odocoileinae* deer dry matter intakes increased with the inclusion of purified spruce bark tannin at levels up to 10% concentration in the diet. This 83 day trial, the first of a series, was conducted during the summer of 2003. The purpose of this trial was to determine if concentration of ST supplements effected deer intake of tannins and also deer performance in a pasture-grazing environment. The second purpose was to determine how performance may be affected by measuring fecal parasite loads and pasture utilization.

The trial consisted of 3 treatments, with 2 replicates of 6 deer in each pen. The three diet treatments were planned to be Low-0%, Medium-8%, and High-16% spruce bark tannin supplemented sun-cured alfalfa pellets. Pellets were offered every morning at 1 kg·head^{-1} as fed from 17 June to 8 September, 2003 to assess feed dry matter intake (DMI). Deer were held in 1 ha paddocks containing a pasture forage mix of alfalfa, smooth brome, quackgrass (*Agropyron repens* L.), Kentucky bluegrass (*Poa pratensis* L.), creeping red fescue (*Festuca rubra* L.), and dandelion (*Taraxacum officianale* L.). Daily weighbacks of feed (±0.2kg) were used to determine actual intake of the supplement and CT. We also measured intake of ST and monitored preference to supplements containing spruce tannins, and investigated the anthelmintic effect of this tannin source

Pasture forage utilization was determined with three randomly-placed, 1.5 m x 1.5m grazing exclosures in each paddock. Forage biomass inside and out was estimated by clipping a 1 m x 0.5 m quadrat, to a height of 2cm. Plots were harvested on days 0, 30 and 83, with forage dried at 60^0 C. Attempts to obtain utilization estimates failed due to low stocking densities and severe grasshopper infestations, thus utilization was removed from the analysis.

Preliminary analysis in the Department of Chemistry at the University of Alberta revealed that spruce bark contained 40% ST, similar to that found in an earlier study (Hudson et al 2000) and as these estimates were congruent, rations were formulated and the trial began. Post-trial analysis by the Agriculture and Agri-Food Canada (AAFC) - Lethbridge Research Center, highly experienced in tannin analysis, revealed that the actual ST concentrations in repeated measurements were 6.1% in the spruce bark. Differences in tannin concentrations within conifer trees has been attributed to sample preparation, extracting solvent, foliage quality, and assay method for the quantification of total phenols and CT (Yu and Dahlgren 2000) and it was decided that due to the extensive experience of AAFC lab personnel and the repeated analysis, to accept the AAFC values were correct. This resulted in pelleted supplements containing only 0.48%, 1.47%, and 2.55% ST in the Low, Medium and High CT diets, respectively, much lower than our planned treatment diets of 0%, 8%, and 16% spruce tannin.

Deer were weighed on days 1, 30 and 83 to measure weight gain, and calculate rates of gain on each diet over the summer feeding period. Fecal pellets were also collected to assess parasite loads on days 11, 30 and 83, and thereby evaluated the anthelmintic effect of ST.

2.2.5. Evaluation of Deer Preference for Quebracho Tannins in the Winter Pasture Trial, 2004

The Winter Pasture 2004 trial was conducted to evaluate a QT supplement source to replace the ST used in the previous trial. The use of QT had the advantage of being readily and commercially available, and is commonly used in feeding trials throughout the world, which facilitates greater comparison of results to other studies. QT is a complex mixture of tannin, flavonoids, and other phenolics (Asquith and Butler, 1985) with typical concentrations in the range of 70-80 % (Rautio et al., 2007), permitting better isonutritional diet formulation. A draw back of their use is that herbivore tolerance of tannins varies with tannin source, and as our QT is sourced from Argentina, we would not expect adaptation North American WTD to a tannin-structure they have never been exposed to.

All deer were offered a control diet of 0.36% CT containing pellets for a period of 8 days prior to the beginning of this trial to allow for adjustment from their previous diet of second-cut alfalfa hay. This trial used the same pens as the Summer Spruce tannin trial with 6 pens of 6 deer, and 3 treatments randomly allocated to pens. Treatments are summarized in Table 2.3 and were designed to allow deer the choice of two types of pellets offered in identical weatherproof gravity fed feeders. Treatments included a low CT control (0.36% + 0.36% pellets), medium CT (0.36% + 6.33% pellets), or high CT (0.36% + 15.18% pellets).

This trial was comparable to dry-lot conditions as foraging was limited by up to 0.8 m of snow, although some feeding on standing cured grasses was observed. Feed was offered ad-libitum and periodic weigh backs (±02kg) were conducted every 4-8 days to estimate DMI. Fecal samples were collected every 2 weeks by collecting and pooling 6 sub-samples of fresh individual pellet groups in the snow and stored frozen until further analysis. Deer were weighed on days 1 and 59 of the trial to determine weight gain.

This trial ran for 59 days from 3 February 3 to 3 April, 2004, after which it was extended until 11 April, 2004. During this extension, 5 deer from the low tannin and 4 deer from each of the medium and high tannin treatments were randomly selected and placed individually inside a barn within pens for 72 hr to get individual estimates of feed intake (±5 grams) during a series of 3, 72 hour holding periods. As only 4-5 pens were available, all awaiting deer were held in outdoor pens on their respective treatment diets.

2.2.6. Digestibility of Restricted Choice Diets Containing Quebracho Supplemented Alfalfa in the Digestibility Trial

This trial evaluated the effect of 3 restricted (i.e. no choice) pelleted diets containing low (0.36%), medium (6.33%) or high (15.18%) levels of QTs, on deer (DMI)(±5g), dry matter (DM) and protein digestibility, weight gain, and urinary chemical indices, in a trial conducted from 3 to 19 April, 2004. Single deer were assigned to 4 pens (25-48 m^2) in each of the three treatments. Deer were weighed on day 1 and 17 of the trial to assess weight gain or loss. One composite fecal sample per pen was collected on days 13, 15 and 17 using 6 sub-samples. Urine samples were collected by placing four deer in individual pens within the urine collection barn. Deer were held for 48 hr during one of three sampling periods during the final 6 days of the trial. Three feed samples, composed of 6 sub-samples of each feed type collected prior to feeding on the 15th, 17th and 19th of April, were analysed for protein and lignin concentrations to determine digestibility. Feed protein and dry matter digestibility's were calculated using lignin as the internal marker where lignin ratios in feed and feces are used to estimate dry matter and protein digestibility's (Church 1976; Owens and Hanson 1992). Lignin is commonly used as an internal marker because it is an indigestible fraction of the plant cell wall (Merchen 1988). The formula used was:

Example

Protein Digestibility= 100-(100*(% indicator in feed / % indicator in feces)*(% nutrient in feces / % nutrient in feed))

Dry Matter Digestibility= 100-(100*(% indicator in feed / % indicator in feces)

2.2.7. Deer Compensatory Weight Gain and Preference for Quebracho Tannins in the Compensatory Gain Trial, Spring 2004

A feeding trial was conducted during the spring of 2004 to evaluate deer compensatory gain, QT intake, and diet selection. Four pens holding two, 2-4 year old bucks were used for each of the 3 QT levels (n=24 deer). This trial lasted 34 days (3 May 3 – 7 June, 2004). The purpose of this trial was to determine if deer exhibited a compensatory growth pattern in the spring season (i.e. is their optimal spring body weight that results in increased rates of gain following winter). The second purpose was to repeat the Winter Pasture Trial in the spring season adding 2 more replicates per treatment and housing deer in bare soil, dry lot pens, to increase power and reduce sources of error. A more accurate scale was also used for measuring feed intake ±5 grams as compared to the ±0.2 kg in the Winter Pasture Trial. Deer were weighed at the beginning and end of the trial (±0.2kg); spring rates of compensatory gain regression analysis involved the weight gain of all 24 deer in determining a relationship between spring MBW and weight gain.

The treatment diets were offered in the followed paired choices, ***ad-libitum***:
low CT control (0.36% + 0.36% pellets), medium CT (0.36% +
6.33% pellets), and high CT (0.36% + 15.18% pellets).

2.2.8. Seasonal Growth Pattern and Appetite of WTD

The seasonal growth pattern of WTD and corresponding appetite (DMI of feed) is important in understanding practical feeding recommendations for producers. It was assessed by calculating the mean rates of weight gain within the 2 control treatments within each of the Summer Pasture, Winter Pasture Trials and the four control treatments of the Compensatory Gain Trials.

2.2.9. Diet Formulations

Three iso-nutritional, sun-cured alfalfa-base pellets (Figures 2.1, 2.2, 2.3) were formulated by Champion Feed Services Ltd. (Westlock, Alberta) to differ in the proportion of condensed tannin on an as-fed basis, containing low, medium, and high concentrations of CT. Initial CT target concentrations in the pellets were set to 0%, 8%, and 16%, respectively. Sources of CTs included spruce bark obtained from Millar Western of Whitecourt, Alberta in the Summer Pasture Trial, and MGM-s quebracho tannin (QT) from Unitan SAICO, Buenos Aires, Argentina, for all subsequent trials.

Spruce bark was collected from the debarking mill from logs harvested the previous fall, dried to constant weight, and ground in a hammer mill to pass through a 4 mm screen. This saw dust like material was added to reground15% protein sun-cured alfalfa pellets, obtained from Legal Alfalfa Products Ltd. in Legal, Alberta, mixed, and then re-pelleted using steam and pressure dyes.

2.2.10. Fecal and Urine Sample Collection and Analysis

Fresh fecal samples were collected during the Summer and Winter Pasture trials by holding deer in the handling facility pens for two hours prior to weighing. Three fecal pellet groups were collected per pen and pooled to produce 1 sample for later analysis during the Summer and Winter Pasture trials. Two fecal samples per treatment for each trial, corresponding to the first and last day of each trial were analyzed for fecal parasite loads. Fecal parasites were evaluated by Prairie Diagnostic Services using the fecal flotation method. This method takes advantage of the low specific gravity of helminth eggs to separate them from the feces (Samuel et al. 1982). The flotation solution has a higher specific gravity than most worm eggs found in fecal samples.

During the digestibility trial, a minimum of 2 samples, comprised of 3 sub-samples, were collected on each of 3 sampling dates per pen, and were used for digestibility calculations. Urine samples were collected through a steel grate floor and liquids flowed through a stainless steel sub-floor plumbing system. All urine was collected and strained into a stainless steel container with an ambient room air temperature of 5^0C during a 48 hour period with a 50ml sample bottle taken and frozen at -20^0C and stored until analysis. Potassium levels were determined by potentiometric assay using a Boehringer Mannheim/Hitachi 912 analyzer that measures voltage using ion selective cartridges (Boehringer Mannheim Canada). Creatinine was measured following (Jaffre 1886) using a kinetic *in-vitro* assay as described by Popper et al. (1937) and Seelig and Wust (1969), and modified by Bartels and Bohmer (1971). Urea was measured using the enzymatic Roche Urea/Bun assay based on Talke and Schuberts method (1965). Cortisol was measured by a solid-phase, competitive chemiluminescence enzyme immunoassay, using the method Immulite/Immulite 1000 Cortisol (Seimens Medical Solutions Diagnostics 2007).

During the collection of urine samples, small amounts of fecal, feed, soil, hair and other particulate contaminates mixed with urine samples in the collection system. As a result, only 2 samples from each of the low and high CT treatments were sent for analysis to Prairie Diagnostic Services Ltd, at the Western College of Veterinary Science, at the University of Saskatchewan, who did not recommend the use of these samples due to the degree of contamination. The results of this limited sampling are reported with this note of caution.

2.2.11. Feed Intake

Pellets were offered at 1 kg per deer per day (Summer 2003) or *ad-libitum* in weekly offerings (Winter Pasture, Digestibility, and Compensatory Gain trials), and orts were subtracted from those offered. The difference was considered the as-fed feed intake, which was then converted to DMI using DM moisture estimates (Association of Analytical Chemists, 2003). DMI were then used in all further calculations of CT intake.

2.2.12. Feed Quality Laboratory Determination

Many laboratory procedures were followed to evaluate feed and fecal quality during this trial. Samples collected were either frozen to -20°C and stored before drying or were dried immediately following harvest to constant weight at 60°C. Dried samples were ground to pass a 1-mm screen using a Wiley Mill. Protein determination of feed forages and feces was made using a LECO FP-528 nitrogen auto-analyzer (Association of Analytical Chemists 1995). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined using the filter bag technique (Ankom Technology Corporation, 2005a, 2005b), that determines acid detergent fibre residue (primarily cellulose and lignin) remaining after digestion with sulfuric acid. Acid detergent lignin determinations (Ankom Technology Corporation, 2005c) were necessary to quantify lignin as an internal marker in the feed and feces, and to calculate nutrient digestibility. Ash determination was conducted as part of the lignin determination procedure. This method quantifies ash in feed materials based on the gravimetric loss by heating to 550°C for a period of at least eight hours (Association of Analytical Chemists 2003c).

2.2.13. Tannin Feed Sampling and Analysis

ST and QT supplemented pellets (see Champion Feeds guaranteed analysis; Figures 2.1 and 2.3) were sampled (Association of Analytical Chemists, 2003c) 3 times during the course of all the trials that utilized these diets. The 3 samples were analyzed twice and averaged during tannin quantification to ensure an accurate measurement. Average tannin concentrations were then multiplied by dry matter intake to estimate tannin consumption. CT determinations were conducted by the Agriculture and Agri-Food Canada-Lethbridge Research Center using reversed-phase high-performance liquid chromatography (Koupai-Abyazani et al. 1992). The same feed samples were used to determine average protein, acid detergent fiber and neutral detergent fiber contents of the diets.

2.2.14. Deer Performance

Weight changes in individual deer were determined by weighing deer (+/-0.2 kg) as they moved deer through a handling system equipped with a compartment housing the scale. Rates of gain were calculated as the difference in body weight between weighing periods. Deer body weights (BW) were expressed as metabolic body weight ($BW^{0.75}$) (MBW) in feed intake calculations to adjust for possible co variation between feed intake and body weight.

2.2.15. Data Analysis

All trials were designed as completely randomized designs, differing in treatments, number of replicates, and dependant variable analysis, in many cases using the same pens. Data were analyzed with Statistical Analysis Software (SAS) systems edition 9.1 (SAS 2002). CT intake was a result of preferential dietary choices between the two offered rations. During the ANOVA, CT treatment level was considered the fixed effect and was assessed in SAS using mixed models. Where significant main effects or interactions were found ($p<0.05$, unless otherwise indicated), post-hoc comparisons of lsmeans were performed using the pdiff multiple comparisons function (SAS 2002) with differences considered significant at $p<0.05$, unless otherwise indicated.

Linear and polynomial regression analysis was used to quantify relationships between the selected condensed tannin intake (% and absolute) and the dependant variables, including dry matter intake, weight gain, dry matter digestibility, protein digestibility, and ratios of urea:creatinine, potassium:creatinine, and cortisol:creatinine. Mixed models, minimum Akaike Information Criteria (AIC) (Burnham and Anderson 1998, Gagne and Dayton 2007) were employed to determine which of either the linear or polynomial regression models best fit the data and the model with the smallest AIC score was chosen as the optimal model for final analysis.

2.3. Results

In general WTD selected diets to contain low concentrations of ST and QT (2.04-5.34%) and regulated tannin intake in all trials and within the most robust trial, the Compensatory Gain Trial, deer regulated QT intake precisely in the range of 2.99-3.41%. The intake of these low concentrations of QT reduced DMI and weight gains. In the Digestibility Trial, medium and high QT concentrations reduced DMI, protein digestibility, urea concentrations in urine, weight gain and perhaps slightly caused an increase in DM digestibility. Total QT intake ($g \cdot kg\ mbw^{-1} \cdot day^{-1}$) of no choice concentrations was reduced in the Digestibility Trial as compared to all other trials where choice was offered. Due to low parasite levels in all deer, the anthelmintic effect of tannins could not be properly evaluated.

2.3.1. Spruce Summer Pasture Trial

All deer MBW among pens and within trials were compared to determine if body weight should be considered a covariate during analysis, with no differences ($p=0.30$ to 0.99) (Table 2.3).

In the Summer Pasture Trial using ST deer exhibited no differences in DMI ($p=0.88$) among 3 iso-nutritional diets containing up to 2.55% ST, with DMI averaging 0.963 $kg \cdot day^{-1}$ (±0.03) after 14 days. Levels of CT intake averaged 2.1% of the diet (assuming daily dry matter intakes of 4% of body weight). During this time deer performance was similar across all treatments ($p=0.31$), with a mean growth rate of 0.62% of body $weight \cdot d^{-1}$. Fecal parasite loads were very low in all deer at the beginning and end of this trial, with no relationship between diet and parasite loads ($F=0.84$; $p=0.51$). The few parasites found were identified to belong to the order *Strongylida* and the genus *Eimeria* and *Cryptosporidium.*

2.3.2. Quebracho Winter Pasture Trial

During the Winter Pasture trial, 1 pen of deer in the low QT treatment escaped by breaking a gate mechanism, leaving only one replicate for this treatment. DMI was similar among diets ($p=0.24$) (Table 2.4) with intakes averaging 130 $g \cdot kg\ mbw^{-1} \cdot day^{-1}$. Deer in the high QT treatment diet consumed the greatest amount of tannin ($p<0.05$), averaging 7.2 $g \cdot kg\ mbw^{-1} \cdot day^{-1}$, 257% more than within the medium treatment, which remained slightly higher but statistically similar to the low tannin treatment (Table 2.4). Deer selected dietary QT concentrations (%) at variable levels among treatments ($p=0.002$), with the amount of QT selected approximately proportional to the QT offered in the diet (Table 2.4). Deer consuming the high and low QT diets (0.26 $g \cdot kg\ mbw^{-1} \cdot day^{-1}$) gained more weight ($p<0.062$) compared to deer on the medium QT diet. In fact, deer exposed to medium QT levels experienced the greatest net weight loss with deer in the low QT diet more similar to the medium QT diet than the high QT diet (Table 2.4). This is likely explained by one pen of the low QT diet data missing as deer escaped resulting in the loss of 1 of the 2 reps for this treatment. Data were entered as missing for this data column in the analysis. This significant difference in weight gain ($p= 0.062$) should be regarded as not significant. Finally, fecal egg and larva counts were similar among all QT treatments ($F=1.12$; $p=0.43$), with the few parasites found from the order *Strongylida* and the genus *Eimeria*.

Regression analysis revealed that QT consumption was closely associated with the amount of QT offered in the diet ($p<0.001$; $R^2=0.98$) (Table 2.5). These results indicate that deer consumed more tannins even when offered a choice where one forage item was low in QT, and suggest deer did not altogether avoid feeds high in QT content. However, when actual and expected QT intakes were compared (i.e. the difference from random foraging patterns), and correlated with QT concentrations in deer selected diets (Figure 2.4), there was a slight pattern for QT avoidance during this trial, suggesting deer have the ability to regulate tannin intake. Notably, both dry matter intake ($p=0.31$) and weight gain ($p=0.27$) (Table 2.5) were not affected by tannin concentration (%) in the selected diet of deer during the Winter Pasture trial.

The extension of the Winter Pasture trial period was analyzed separately from the main trial. Dietary treatment did not effect dry matter feed intake ($p=0.85$) but did effect QT concentration (%) in the diets that deer selected ($p<0.0001$) as well as QT actual intake ($g \cdot kg\ mbw^{-1} \cdot day^{-1}$) ($p<0.0001$) (Table 2.6). Deer exposed to the high QT diets consumed the most QT at 7.4% and 8.6 $g \cdot kg\ mbw^{-1} \cdot day^{-1}$ (Table 2.6), which is what would be expected if deer were foraging at random (Figure 2.4). Regression analysis of the extension period data revealed that although deer selected greater QT in their diet when presented with feeds containing greater QT ($p<0.0001$; $R^2=0.98$), DMI levels were ultimately not associated with the level of QT present in actual deer diets ($p=0.50$) (Table 2.7).

2.3.4. Quebracho Digestibility Trial

In the 17 day restricted choice QT feed trial, penned deer were offered one of 3 alfalfa diets with low, medium, or high QT concentrations as a sole source of feed. Forced exposure to QT had a major effect on DMI ($p<0.0001$). Deer within the low QT diet consumed the greatest ($p<0.05$) amount of feed (95.8 $g \cdot kg\ mbw^{-1} \cdot day^{-1}$), translating to 163% and 314% more feed than the medium and high tannin diets, respectively (Table 2.8). QT intake (g·kg mbw^{-1}·day^{-1}) was lower ($p<0.05$) within the low QT treatment compared to both the high and medium QT diets (4.64 and 3.72 g·kg mbw^{-1}·day^{-1}, respectively).

Feed DM digestibility varied among the treatments ($p<0.008$), being greater ($p<0.05$) within the medium and high QT diets compared to the low QT diet (Table 2.8). Although protein digestibility also varied among treatments ($p<0.10$), the treatment effects were markedly different from the pattern observed for overall DM digestibility's. Deer consuming the low QT diet experienced the greatest protein digestibility of 46.7 %, a value 11.6% greater than that observed for the high QT diet (Table 2.8). Deer consuming the medium QT diet had a protein digestibility similar to that of both the high and low QT diets.

Weight gain was also effected by QT in the diet ($p=0.04$) (Table 2.8). Deer consuming the low and medium QT diets had similar weight gains of ±2.1 and -3.57 (g·kg mbw^{-1}·day^{-1}), while deer on the high tannin treatment experienced the greatest weight loss of -17.1 (g·kg mbw^{-1}·day^{-1}) (Table 2.8). Weight loss values under the latter treatment were considered extreme and influenced the maximum duration of this Digestibility Trial (i.e. 17 days).

Despite careful pre-trial washing of the urine collection facility, urinary samples collected from these deer were contaminated by small amounts of feces, hair, and dust. Consequently, laboratory technicians at the Prairie Diagnostic Services lab advised us that these samples were likely too contaminated to provide accurate data on deer metabolic conditions. Nevertheless, four samples belonging to 2 deer of each of the high and low treatments were submitted for analysis. Both potassium:creatinine and cortisol:creatinine ratios were not affected by diet ($p>0.05$) (Table 2.9). However, the urea:creatinine ratio ($p=0.04$) did vary between these treatments, being 3.5 times greater in the low QT treatment than that of the high QT (Table 2.9).

Regression analysis revealed that increasing QT concentrations (%) in the diet of restricted choice fed deer was associated with a linear reduction in dry matter intakes ($p<0.0001$; $R^2=0.85$) and protein digestibility ($p=0.02$; $R^2= 0.40$) (Table 2.10).

As might be expected, QT intake (g·kg mbw^{-1}·day^{-1}) increased with QT exposure in the diet offered to deer ($p<0.0001$; $R^2=0.91$) (Table 2.10), although this association followed a logarithmic pattern (Figure 2.5). Polynomial regression also identified that dry matter digestibility increased at medium levels of QT in the diet, but then declined slightly with a dietary shift to high QT levels ($p=0.008$; $R^2=0.66$) (Table 2.10). Deer weight gain was found to decline linearly with increased forced exposure to QT in the diet ($p<0.01$; $R^2=0.53$) (Table 2.10). Finally, among the 3 urinary indices assessed, only the urea:creatinine ratio (U:C) was associated with QT in the diet (Table 2.11). U:C declined as the proportion of QT increased in WTD diets ($p<0.04$; $R^2=0.92$).

2.3.5. Spring Compensatory Gain Trial

Within the Compensatory Gain Trial, deer DMI were equivalent among all treatments ($p=0.17$), averaging 157 g·kg mbw^{-1}·day^{-1} (Table 2.12). Total QT intake (g·kg mbw^{-1}·day^{-1}) was much lower ($p<0.05$) within the low QT treatment compared to either the medium or high QT diets where deer regulated QT intake to 4.6 to 5.0 g·kg mbw^{-1}·day^{-1} (Table 2.12). QT concentration (%) in the selected diets of deer followed the same pattern as tannin intake, with deer in the medium or high tannin treatments regulating diet QT concentration to a maximum of 3.0 to 3.4% (Table 2.12). Despite similar DMI levels, deer weight gains were greater ($p<0.05$) in the low QT treatment (11.82 g·kg mbw^{-1}·day^{-1}) compared to the others and similar between the medium and high QT treatments where weight gains ranged from 6.6 to 9.7 g·kg mbw^{-1}·day^{-1} (Table 2.12).

As expected, a strong positive relationship was observed between QT concentration (%) in the offered diet and QT concentration in the selected diet ($p<0.0001$; $R^2=0.96$), although this relationship followed a logarithmic pattern (Table 2.13) (Figure 2.6), deer did not forage at random (Figure 2.4). Total QT intake (g·kg mbw^{-1}·day^{-1}) also increased in a logarithmic pattern with increases in QT concentration in the selected diet ($p<0.0001$) (Table 2.13) (Figure 2.7), with predictions of selected QT intake reaching a maximum of 6 g·kg mbw^{-1}·day^{-1}. DMI (g·kg mbw^{-1}·day^{-1}) had a negative relationship with QT % in the selected diet (p=0.069) (Table 2.13) with QT concentration causing a decrease in DMI (Figure 2.8). Weight gain of deer ($g \cdot kg\ mbw^{-1} \cdot day^{-1}$) showed a negative relationship with both QT concentration (%)(p=0.088) in the selected diet and the total QT intake ($g \cdot kg\ mbw^{-1} \cdot day^{-1}$) (p=0.075) Table (2.13)(Figures 2.9 and 2.10).

Regression analysis in this trial also assessed whether spring metabolic body weight (MBW) was linked to compensatory weight gain ($g \cdot kg\ mbw^{-1} \cdot day^{-1}$). However, no relationship was found between initial MBW and ensuing rates of compensatory growth (p=0.47) (Table 2.13) suggesting that initial animal size does not impact expected rates of compensatory gain in WTD.

In a further attempt to quantify the seasonal growth rates of deer, individual WTD rates of gain on the low QT control diets within all trials conducted from June 2003 to June 2004 (minus the missing data from mid October to January) were plotted. A highly seasonal growth rate was identified with deer rate of gain sharply increasing in late April and mid May (11.8 $g \cdot mbw\ kg^{-1} \cdot day^{-1}$). Deer rates of gain reached a maximum (16.9 $g \cdot mbw\ kg^{-1} \cdot day^{-1}$) in early July before beginning to decline slightly in late summer and fall (Figure 2.12). This high rate of gain in spring also coincides with a sharp increase in DMI from 110 $g \cdot mbw\ kg^{-1} \cdot day^{-1}$ in early April to 157 $g \cdot mbw\ kg^{-1} \cdot day^{-1}$ in May, an increase of 43% (refer to Tables 2.4, 2.6, 2.8, and 2.12 control diet DMI's).

2.4. Discussion

Condensed tannins are known to affect ruminant performance in both positive and negative ways. This study of WTD proved to have several challenges, one of which being the variability of deer and the necessity to accurately assess response variables with the most robust experiments possible, which we improved upon during the course of this study. WTD preferred low to moderate CT concentrations and regulated their intake precisely, yet their intake came at a cost as they reduced weight gain by reducing feed intake and protein digestibility. This anomaly draws researchers to ask several questions including: why do deer prefer to consume CT and what specific positive functions do they serve that offset this apparent negative cost?

Are WTD preferences and effects of tannin intake similar to other species and studies? Do different tannin sources affect WTD differently?

This study provides a unique look into the nutrition and performance of WTD, and although it did not fulfill all of its objectives, several unique observations have been identified that warrant further discussion.

2.4.1 Deer Performance

Deer performance (i.e. weight gain) is the primary index by which researchers can cost effectively determine the feed value of CT supplementation. ST supplementation at low concentrations did not affect summer pasture weight gain of deer, and due to its limited use we were not able to extensively compare the two CT types, with the literature indicating that CT source has different effects on ruminant digestion (Makkar and Becker 1998; Rautio et al., 2007). QT supplementation in the Winter Pasture Trial also did not affect deer weight gain but it approached significance and was likely the result of one missing replicate in the control diet. However using similar treatments in the Compensatory Gain Trial, but with increased replicates and measurement accuracy, we were able to determine that light to moderate concentrations of QT inhibit WTD weight gain. Similar weight losses have been documented in mule deer at concentrations in this range (Robbins et al. 1987). Large differences in subsequent weight gain were identified at medium and high QT supplementation in the Digestibility Trial, and lead us to recommend that WTD on high QTs 6-15% with no other source of feed available compromise deer survival as one deer lost 7.7 kg in the 17 day Digestibility Trial. With the question of the effect of CT's on weight gain in WTD answered it now becomes important to determine how WTD were affected by QT.

2.4.2. Tannin Selection

Ruminants generally select against tannins in their natural forages (Cooper and Owen-Smith, 1985; Cooper et al., 1988; Distel and Provenza, 1991; McArthur et al., 1993) with Cooper and Owen-Smith (1985) not detecting aversion to CT below 5%, very similar to this study. CT concentrations in the range of 2-4% are generally accepted to provide optimal benefits (Barry, 1983; Barry and Manley 1986; Schreurs et al., 2002). QT consumption in this study appeared to be regulated quite precisely ranging 3.0-3.4% (Compensatory Gain Trial) and 2.0-5.2% (Winter Pasture Trial) consistent with those found in mule deer fed QT diets who selected 3.5% QT (Robbins et al., 1991). Across all the trials WTD selected a diet containing 3.6-7.4% QT which include the high intake from the 72-hour extension period of the Winter Pasture Trial during which WTD DMI was equivalent to a random foraging pattern. This supports the notion that diet preference develops with exposure to a food toxin (Pliner, 1982), resulting from digestive malaise and feedback mechanisms in accord with the aversion learning theory (Provenza, 1995, Provenza et al., 2000; Villalba and Provenza, 2001) and not astringency and palatability (Kumar and Singh, 1984). If the latter were the case we would expect a quicker aversion to the diet (i.e. recall deer were consuming the same diet treatments for the previous 59 days during which a preference pattern was established with QT intake lower than this). Waghorn et al., (1994) also suggested that decreased ruminal turnover and rate of digestion was more important than palatability in reducing the intake of sheep consuming tannin rich forages. Animals adapt to tannin consumption by increasing salivary production (Van Soest 1994; Mehansho 1987) to ease the aversive effects of tannin toxicosis (Provenza et al., 2000; Villalba and Provenza, 2001) and are capable of learning to balance food choice and intake to reduce tannin effects (Silanikove et al., 1994; Silanikove et al., 1996; Titus et al., 2001). We concur with Rautio et al. (2007) who recommend that short duration tannin preference trials not be used due to fluctuating patterns of preference and who further recommend that only those results of trials performed long enough for a stable pattern to become evident—be it a constant level of selection or a consistently repeated preference cycle, should be evaluated.

QT consumption by roe deer (_Capreolus_ _capreolus_) in a 43 day study (Clauss et al., 2003) was approximately 25% of the average of the current studies spring compensatory feeding trial suggesting WTD can tolerate on average higher levels of QT than roe deer. Significant variations exists among individual animals as on roe deer selected a diet that contained 3.5% QT. Benefits of (2-4%) tannin intake are attributed to the protection of proteins from microbial digestion in the rumen that increases by-pass protein and amino acid absorption and efficiency of protein utilization (Makkar et al., 1995; Leng 1997; Aerts et al., 1999; Ramirez-Restrepo and Barry 2005; Klieve et al., 1996), as well as providing anthelmintic benefits (Nguyen et al., 2005) . Although one of the objectives of this study was to assess known anthelmintic effects of tannins, we are unable to draw any conclusions due to low parasite levels in all deer.

Tannins above 5% can become an anti-nutritional factor in plant material fed to ruminants (McLeod, 1974) and at higher levels (5– 9%) have an adverse effect on intake (Marten and Ehle, 1984) and rumen function (Barry, 1983; Barry, 1985 and Norton and Ahn, 1997;) as they reduce digestibility of fiber in the rumen (Reed et al. 1985). Reduced digestibility by CT inhibiting the activity of bacteria (Chesson et al. 1982) and anaerobic fungi (Akin and Rigsby, 1985) and complexing with proteins (Van Sumere et al. 1975), cellulose, pectin, starch, and alkaloids (Swain 1965; Haslam 1979). The effects of high QT supplementation on weight gain are evident in this study. Interestingly, across all trials, tannin consumption averaged 4.8 g·kg mbw^{-1}·day^{-1} and did not exceed 8.6 g·kg mbw^{-1}·day^{-1} suggesting an upper tolerance of tannin intake by WTD within this range. The fact that WTD in this study consumed tannin at a concentration which caused reduced rates of weight gain can partially be explained by Barry and Duncan, (1984) who suggested that optimal CT concentrations for protein digestion may cause depressions in metabolizable energy intake, which could reduce weight gain.

Beyond 2-4 % tannin protein binding can become excessive limiting protein availability and causing system toxicity (Dollahite et al., 1966; Martin et al., 1987), altering physiological systems, requiring detoxification with absorbed phenolics (Meyer and Karasov, 1989) and increasing energy demands, as elimination of tannins incurs a metabolic cost (McArthur and Sanson 1993). Liver and kidney damage can occur (McLeod 1974; Robbins et al., 1987a) if the rate of CT intake is not balanced with detoxification.

In all trials within this study WTD consumed consistently low to moderate amounts of CT behaving similar to mule deer (Robbins et al. 1987a). This intake is likely linked to how quickly an animal can detoxify these chemicals (Foley and

McArthur, 1994), which generally involves conversion of more toxic lipophilic compounds to water-soluble compounds that are then excreted in the urine and feces (Cheeke and Shull, 1985; Cheeke, 1998; McArthur and Sanson 1993). QT at high concentrations can affect the mucoproteins and the epithelial cell lining of the digestive tract, which reduces digestive performance causing gastritis, slowed the propulsion of feeds, and constipation (Kumar and Singh 1984). Impeded passage rates and may have played a role in increasing DM digestion in this study (see section below).

2.4.3. Protein Digestibility

The chemical basis for the defensive role of tannins has been attributed to their ability to precipitate plant proteins and gastrointestinal enzymes (Van Sumere et al. 1975, Haslam and Lilley, 1988). Enzyme loss impedes the break down of proteins and starches (Quesada et al., 1995), as well as cellulose (Petersen and Hill, 1991), thereby reducing protein and cell wall digestion in the rumen (Butler, 1989; Zucker 1983; Rhoades and Cates, 1976). CT from different plants varies greatly in their capacity to bind carbohydrates and proteins (McAllister et al., 2005).

Protein digestibility reductions as a result of increased CT intake in this study support similar results found in mule deer (Robbins et al., 1987a) consuming high CT concentration plants. Based on the mean regression equation of all of the plants tested (Robbins et al. 1987a), which were found to vary greatly, a CP digestibility reduction of 5.1% is predicted in deer consuming a diet containing 15.3% QT. Deer in this study experienced a CP digestibility decrease of 4.3% and 9.6% in the medium and high tannin treatments. Robbins et al., (1987a) found that the fireweed (*Epilobium angustifolium*) bound the most bovine serum albumin, lending to a predicted reduction of 9.1% in protein digestibility based on a tannin concentration of 15.3%, equivalent to our high tannin treatment reduction of 9.6%. Protein digestibility estimates of deer in this study (47%) were lower than expected compared to other studies involving mule deer fed alfalfa (76.9%)(Smith 1952) wheat herbage (79%) or high grain diets (76%) (Robbins et al., 1987a), grain alfalfa pellet (68%) (Robbins et al., 1991) and goats fed early bloom alfalfa (72%) (Coleman et al., 2003).

The variations in digestibility is likely due to the use of lignin as an internal marker, as similar lower digestibility trends than expected were apparent in the DM digestibility estimates within this study. Lignin was used as an internal marker and although it is considered indigestible, erratic results frequently have been reported when a given marker is applied across a wide range of forages or in different laboratories (Cochran et al., 1987). It is suggested that despite imprecision in marker procedures, inherent variation may be small relative to other sources of variation (e.g., gut physiology, diet, environment, and feed intake). Even though absolute digestibility values may be imprecise and inaccurate, marker-based estimates usually provide reliable information about the direction and extent of kinetic changes induced by treatments (Owen and Hanson 1992). Norton and Ahn, (1997); Osbourn et al., (1971) further recorded confounding influences of tannins in the chemical estimation of lignin on the results of animal digestibility measurements involving tannins where an apparent net gain of lignin through the digestive tract was observed (Osbourn *et al.* 1971). (See Rymer, (2000) for a review of digestibility studies using markers).

Protein digestibility by tannin in-vivo in mule deer was only 12% of the amount of the protein precipitated in-vitro, suggesting other factors play an important mitigating role in reducing the negative effects of QT on intake (Robbins et al.,1987a). One possible reason for this difference has been attributed to deer production of proline rich saliva (Mehansho et al. 1987), with a high capability and affinity to bind tannins during mastication, (Provenza and Malachek 1984; Robbins et al 1987a), the act of which has been shown to reduce the protein binding ability of tannins by 50% in mule deer and goats (Robbins et al 1987a, Provenza and Malachek 1984). QT supplements in the medium and high QT treatments of the Digestibility Trial were added during the pelletting process, involving heat and pressure. This likely prevented the salivary proteins from complexing with the QT as they likely had previously been bound to liberated plant proteins (Joslyn and Goldstein 1964). Similar binding has been found to reduce the extractability of tannins, rendering them less harmful (Price et al., 1980), which has been suggested to reduce the protein tannin bond strength under anaerobic conditions in the rumen as compared to those formed in the aerobic conditions of drying (Leng, 1997). This is a reasonable explanation as to why DMI, total tannin intake and weight gain of deer were lower in the Digestibility trial as compared to the Winter Pasture Trial where WTD consumed similar or higher amounts of total tannin and did not experience great weight loss.

Further explanation includes the fact that the binding capacity of mule deer saliva is limited and where the concentration of QT in the diet exceeds that which can be bound, tannins begin to be metabolized and become a determinant of dietary selection (Robbins et al., 1991). Tolerance of plant secondary compounds increases with diet choice, and (in the Digestibility Trial) WTD did not have a choice of feed (Dearing and Cork, 1999; Burritt and Provenza, 2000) which likely caused the reduction in DMI, as animals consuming single feeds with toxins inundate detoxification pathways and constrain feed intake (Freeland and Janzen, 1974). When given a choice of feeds containing different toxins, animals eat more feed than animals given only 1 feed (Dearing and Cork, 1999; Burritt and Provenza, 2000).

Provenza et al. (2003) suggested that biochemical diversity is critical for ingesting both nutrients and toxins which supports our findings of increased tannin consumption and DMI in trials where deer were offered a choice and allowed to select a diet. DMI was 1.8 times greater in the Winter Trial as compared to deer in the medium tannin treatment in the Digestibility Trial who consumed similar amounts of tannins. Ruminants fed using choice of feed will select the most nutritionally available components and reject the least valued materials (Boodoo et al. 1988; Aboud et al. 1990), although this does not always occur. Goats have been found to select much lower quality forage in order to avoid tannin intake resulting in weight loss as compared to the alternative feed (Provenza and Malachek 1984). This diet diversity and allowance for selection is a probable reason why free ranging deer have the ability to detoxify toxins better than penned deer (Harborne 1977).

Beyond 2-4 % tannin protein binding can become excessive limiting protein availability in sheep (Martin et al., 1987). Although WTD are efficient at recycling urea (Chaplin 1987), rumen bacteria require a minimum of 8% CP in the rumen for proper fermentation which could have played a part in the reduction of digestive performance of these WTD. Absorption and metabolism of CT requires detoxification, an energy and nutrient demanding process and would reduce net energy and protein for growth (Freeland and Janzen, 1974; McArthur and Sanson 1993; Illius and Jessop, 1995) and contribute to weight losses.

2.4.4. Forage Digestibility and Feed Intake

Inhibition of microbes by tannins leads to reduced fiber and cell wall digestion in ruminants (Norton 1994; Nelson et al., 1997, Schofield et al., 2001; Barry and Manley 1984; Barry et al., 1986; Makkar et al., 1995, Klieve et al., 1996; Leng 1997). This was not true in mule deer NDF digestion (Robbins et al., 1987a), where deer were consuming low and high tannin diets. Instead NDF digestibility was a highly predictable function of the forages lignin, cutin, and silica content (Robbins et al., 1987b). Robbins et al, (1987b) further suggested that a slight increase in NDF digestibility in grass blended mule deer diets high in tannin was caused by a reduction in passage rate arising from an increase in less digestible fiber of the grass (Mould and Robbins 1982; Baker and Hansen 1982; Van Soest, 1994) as deer are not adapted to digesting the high cellulose contents of grasses (Hans-Joachim, 1997). We attribute the increased WTD DM digestibility in this study to the reduction in DMI and subsequent decrease in passage rate, but speculate that gut fill was not a factor. If gut fill was affecting deer digestion we would expect a distended rumen and increase in rumen size (Waghorn et al., 1990). Visual observations noted during the study described deer as more "empty" as opposed to "full" and attribute tannin toxicity as a major factor in DMI.

Deer dry matter digestibility estimates in this study (Low=27%, Medium=32%, and High 45%) were much lower than the literature. Early bloom alfalfa dry matter digestibility in goats was 66% (Coleman et al., 2003). Typical dry matter digestibility's for alfalfa are 55.2% and cell wall digestibility 39.2% in mule deer (Robbins et al 1987b). The reduction of cell soluble digestibility averaged 2.8 times the reduction in protein availability caused by tannin intake (Robbins et al 1987b). Mule deer consuming a basal pellet diet of alfalfa-grain containing 14.8% crude protein and 37.7% NDF (Robbins et al. 1991) had a dry matter digestibility of 63% (this study had 16% CP and 46% NDF).

Robbins et al.(1987a,) found that mule deer DMI was reduced 50-60% in deer grazing high phenolic leaves and flowers as compared to intake of diets low in phenolics equivalent to the medium tannin treatment in this trial (61% reduction in dry matter intake). Very high QT concentrations (15.33%) fed to deer in this trial exceed all other reported results in the literature, which realized a further reduction in DMI to 31% of the control diet.

We therefore conclude that both DM and protein digestibility's were lower than expected in all our dietary treatments, as compared to the literature. We support the direction of the effects (i.e. increase in DM digestibility) due to the discussion of the use of lignin as an internal marker (see protein digestibility section discussion on the variability of lignin marker estimates). Tannins reduce neutral detergent soluble digestibility (Robbins et al 1987b) and DMI, which combined with tannin toxicosis likely all contributed to the observed rapid weight loss in high QT treatment deer in the Digestibility Trial of our study

2.4.5. Spruce and Tree Tannins

Types and levels of secondary compounds including tannins can vary between species, within a species (2.2% to 25.3%), and among genotypes, plants parts, growing seasons, habitats, and soils (Swain, 1965; Barry and Forss, 1983; Sehgal, 1984; Waterman et al. 1984; Joshi et al., 1985;Palo and Robbins, 1991; Ossipova et al., 2001; Salminen et al., 2001; Kobue-Lekalake et al., 2007; Rautio et al 2007). Tree bark in some species may contain as much as 15% CT (Dalziel, 1948), while young leaves are higher in tannin content than older leaves (Provenza 1984; Vaithiyonathan and Singh, 1989), with immediate tannin mobilization (within an hour) following browsing reported in some species (Van Hoven, 1991). Such variability increases the complexity of tannin study in forage diets. Tannin concentrations in white spruce are variable with 40% found in bark (Sporns as cited by Hudson et al., 2000), 0.011% CT in spruce limbs within 2 m of the ground (Bauce et al., 2006) and 8% CT in the plant (Suave and Cote (2007). The latter value is consistent with this study. Suave and Cote (2007), found that wild WTD at high densities selected 70% balsam fir (*Abies balsamea*) and 20% white spruce (*Picea* glauca) in their diet whereas captive deer in cafeteria trials selected 89.9% balsam fir and 10.1% spruce. Assuming 8% CT levels, WTD would be consuming an estimated 0.8-1.6% of their diet in spruce tannins with an additional unknown amount of other tannins being consumed in the rest of the diet. Spruce tannin consumption in the Summer Trial was up to 2.55% with no other tannins available. These intakes are much lower than in WTD and mule deer found to consume up to 10% ST in the diet during a second feeding trial (Hudson et al., 2000). This suggests that WTD or their microbes may have developed a tolerance to this endemic source of tannins in spruce.

Differences in tannin concentrations within conifer trees are attributed to variable sample preparation, extraction solvents, foliage quality, and assay method for the quantification of total phenols and CT (Yu and Dahlgren 2000; see Schofield et al., 2001, for a review of numerous methods of tannin analysis). ST analyses are further affected by initial harvesting, drying and extraction methods of tannins, and nitrogen content (estimates ranged from 5-86%) with it suggested that the water-soluble CT fraction of spruce may have the greatest physiological and/or ecological significance (Yu and Dahlgren 2000). Consequently, it is not surprising that the CT concentrations analyzed by the two laboratories in this study were different. We remain confident that the results of AAFC analysis are correct and as this lab was used in all other tannin analysis within this study, it facilitates more valid comparisons of the results between trials. Haegerman and Butler (1989) reviewed the subject of choosing the appropriate methods and standards for assaying tannin and since then have been comprehensively reviewed (Waterman and Mole 1994; Mueller-Harvey 2001). Hagerman and Butler, (1989) and Makkar, (1989) suggest that protein precipitation assays better correlate with the nutritional values of tannin-rich feeds.

This study suggests that the ST source is not high enough in CT concentration to be useful in the formulation of iso-nutritional diets in CT supplemental studies at least without further tannin purification. Voluntary WTD intake of spruce bark may also be affected by other secondary compounds such as camphor, which is known to deter DMI (Harborne 1991, 2001) possibly reducing the suitability of ST supplements. Alternatively, QT is readily available and commonly used in feeding trials, which facilitates greater comparison of results but has several concerns with their use (reviewed by Rautio et al., (2007).

2.4.6. Urine Chemistry

Urinary urea, potassium, and cortisol concentrations are cost effective and noninvasive indices that are usually interpreted together to index a WTD's nutritional environment. Cortisol is an indicator of stress (Wesson et al. 1979; Seal and Bush 1987) and serves an important function in mobilizing body fat and protein to be used as energy sources during nutritional deficiencies (Granner 1985). Potassium can indicate nutritional restriction with high values, reflecting cell destruction and potassium release from tissues in starving animals (DelGiudice 1995). Urea typically indicates dietary and body tissue protein metabolism with urea nitrogen constituting 85% of urinary nitrogen (Wallin 1979). These indicator concentrations are expressed as ratios to creatinine to correct for urine dilution (Coles 1980; DelGiudice et al. 1988a).

In this study cortisol:creatinine ratios were similar between treatments but were 2.5 times greater than those reported by Hudson et al., (2000). It is possible that our deer were more stressed, than in the previous study, but not likely as a result of nutritional stress, as deer on the control diet experienced weight gains during this trial. Potassium:Creatinine ratios were also similar among treatments and only slightly (30%) greater than Hudson et al. (2000), not indicative of nutritional restriction. Urea:creatinine (U:C) ratios in the control diet in this study was similar to those found by Hudson et al., (2000) both of which were much greater than U:C ratio of WTD fed the high QT diets in this study. U:C ratios decrease with moderate dietary protein restrictions while at severe restrictions (<6% dietary protein) U:C ratios increase rapidly (Warren et al. 1982; DelGiudice et al. 1987b, 1990, 1994; Saltz and White 1991) and are attributed to net catabolism of body protein (Torbit et al. 1985, DelGiudice et al. 1990) and are highly linked to body mass loss (DelGuidice 1994). WTD have an excellent ability to conserve nitrogen when protein intake is restricted by increasing urea recycling, thus reducing its loss in urine (Robbins et al. 1974). With the high dietary protein excellent (15%) used here, the low U:C is likely indicative of moderate protein restrictions caused by the high QT concentration limiting protein digestibility, with similar results reported in mule deer (Robbins et al., 1987).

2.4.7. Compensatory Growth

White-tailed deer vary food intake throughout the year, even when high quality food is freely available (Short et al., 1975), which is consistent with this study. Deer DMI across all trials in this study was moderate in the Winter Pasture Trial, lowest in early April during the Digestibility Trial, and greatest in the Spring Compensatory Trial. Observations of variation in annual food consumption patterns of deer are numerous (Long et al. 1965, Silver et al., 1969; Ozoga and Verme 1970; Worden and Pekins 1995; Hudson 2000). Although no deer body weight could be predicted to gain more weight than another, the trial analysis could have been confounded by differences in body condition. To our knowledge no body condition scoring system is available for WTD and although deer were rejected during selection (with a poor overall body condition) it was noted that this could still be a factor affecting our results. In future studies it is recommended that this source of error be minimized.

As expected, deer weight gain was more efficient in the spring of the year with deer gaining 11 g mbw$\cdot$kg$^{-1}\cdot$day^{-1} more weight than deer in the Winter Pasture Trial, a 12 fold increase in weight gain, with only a 28% increase in DMI. Strong annual seasonal patterns have been reported in WTD, including seasonal rhythms in heart rates, activities, and metabolism Moen, (1978), with the lowest metabolism occurring in the winter, beginning to rise in March and April, and peaking in summer in lactating females (about four times baseline metabolism). The annual cycle of growth and appetite is considered part of a complex adaptive system to enhance survival in a harsh seasonal environment followed by a mild seasonal environment (Moen, 1978; Suttie et al., 1983). These cycles are more pronounced in temperate or arctic species and are synchronized by photoperiod (Hudson 1987). Although the notion of seasonal changes in metabolic rates is now disputed (Mautz et al., 1992), it remains accepted that deer do have substantially increased metabolic demands during spring and summer due to changes in activity (Swift 1946), feeding behavior and physiological processes. These characteristics are accompanied by organ morphology and body composition changes that would be expected to result in changes in metabolic requirements (Mautz et al., 1992). Thus, the nutrition of deer during late spring and early summer becomes favorable for animal production because of the combination of a high intake rate of digestible foodstuffs and a rapid rate of passage of the ingested foods through the animal, which increases the volume of rumen metabolites available to the ruminant (Short 1975).

2.5. Conclusions

The results of condensed tannin supplementation in this study generally support those found in other deer species. From this study we can conclude that:

1. QT concentrations as low as 2.99-3.41% reduce deer weight gain and dry matter intake, and at concentrations between 6-15 %, severely reduced weight gains, DMI, and to a lesser degree protein digestibility.
2. White-tailed deer prefer low to moderate amounts of QT (2-5%) in their diet, and have the ability to regulate their intake quite closely which indicates that some benefits are obviously not yet explained.
3. We cannot conclude whether ST or QT has different effects on WTD performance and parasite loads.
4. The process of pelletizing feeds after the addition of QT may inhibit WTD tolerance of QT.
5.

2.6. Implications

This research has improved our understanding of WTD adaptations to CT, but has raised many new questions. Although deer do select for tannins in their diet, at this time we can not identify any benefits for their supplementation, which necessitates future research in this subject area. Furthermore, as ungulate adaptations to CT are plant and animal species specific, similar studies must be conducted on local tannin sources, in longer duration trials, at suggested concentrations of 2, 4, 6, and 8% CT, utilizing more powerful experimental designs.

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2.8. Tables

Table 2.1. Summary of dietary treatments including condensed tannins (CT) used in the Summer Pasture (Pa), Winter Pasture, Digestibility, and Spring Compensatory Gain supplementation trials.

		Dietary Treatments				
Trial	**Tannin Source**	**Low CT (%)**	**Medium CT (%)**	**High CT (%)**	**n**	**Deer/Pen**
Summer Pasture	Spruce	0.48 +Pa	1.47 + Pa	2.55 + Pa	2	6
Winter Pasture	Quebracho	0.36 + 0.36	0.36 + 6.33	0.36 + 15.2	2	6
Digestibility	Quebracho	0.36	6.33	15.2	4	1
Spring Compensatory Gain	Quebracho	0.36 + 0.36	0.36 + 6.33	0.36 + 15.2	4	2

Table 2.2. Summary of dependant variables assessed in the Summer, Winter, Digestibility, and Spring Compensatory Gain trials.

	Trial			
Data Measurements	**Summer Pasture**	**Winter Pasture**	**Digestibility**	**Spring Compensatory Gain**
Dry Matter Intake	yes	yes	yes	yes
Seasonal Performance	yes	yes	yes	yes
Tannin Intake	yes	yes	yes	yes
Parasite Loads	yes	yes	no	no
Pasture Utilization	yes	no	no	no
Urine Chemistry	no	no	yes	no
Compensatory Weight Gain	no	no	no	yes

Table 2.3. White-tailed deer metabolic body weights at the beginning of the Summer Pasture, Winter Pasture (including Winter Extension), Digestibility, and Compensatory Gain trials.

Trial	Metabolic body weight (SE)	P>F (Pen effect)
	----------(kg)---------	
Summer Pasture	12.8 (0.5)	0.90
Winter Pasture	15.3 (0.9)	0.99
Winter Extension	15.2 (0.8)	0.96
Digestibility	16.2 (0.8)	0.71
Spring Compensatory Gain	16.4 (0.9)	0.30

Table 2.4. Winter Pasture quebracho tannin (QT) supplementation responses of white-tailed deer offered one of 3 QT dietary levels under free choice conditions.

Factor	Dry Matter Intake (SE)	QT Selection (SE)	QT Intake (SE)	Weight Gain (SE)
	(g·kg mbw^{-1}·day^{-1})	-(%)-	----(g·kg mbw^{-1}·day^{-1})-----	
F-value	3.14	106.3	57.5	*14.9*
P-value	0.24	**0.002**	**0.02**	***0.06***
Low CT	132.9 (2.2)	0.36 (0.2)c^{z}	0.5 (0.5)b	-0.86 (0.16)a
Med CT	124.6 (3.2)	2.04(0.2)b	2.8 (0.4)b	-0.96 (0.24)b
High CT	133.9 (2.2)	5.34(0.2)a	7.2 (0.4)a	0.26 (0.16)a

^{z}Means in columns with different letters are significantly different $p<0.05$

Table 2.5. Effect of actual quebracho tannin (QT) concentration in white-tailed deer selected diets on dry matter intake and weight gain, and the effect of QT % in free choice offered diets on QT intake during winter 2004.

Response	Dry Matter Intake	Weight Gain	QT in Offered Diet on QT Intake
	-------------------------(g· mbw kg^{-1}·day^{-1})------------------		
F-value	2.21	2.75	149.1
P-value	0.31	0.27	**<0.001**
R^2	0.69	0.73	0.98
Equation	n/a	n/a	$Y= -0.080+0.945x$
RMSE	n/a	n/a	1.625

Table 2.6 Diet Seelction by White-tailed deer offered on of 3 Quebracho tannin (QT) levels under free choice conditions during a 72 hour extension of the Winter Pasture Trial

Response	Dry Matter Intake (SE)	QT Intake (SE)	QT Selection (SE)
	---------------(g mbw kg^{-1} day^{-1})-------		--------------(%)------------
F-value	0.16	25.8	361.8
P-value	0.85	**<0.0001**	**<0.0001**
Low CT	115.3 (13.4)	0.38 (0.76)c^{z}	0.36 (0.2)c
Medium CT	105.1 (12.0)	3.90 (0.85)b	3.59 (0.12)b
High CT	108.7 (13.4)	8.57 (0.85)a	7.37 (0.2)a

^{z}Means in columns with different letters are significantly different $p<0.05$.

Table 2.7. Effect of quebracho tannin (QT) concentration in selected diet on deer dry matter feed intake, and the effect of tannin content in offered diet on tannin content in selected diet during the 72 hour winter extension period in April 2004.

Response	Dry Matter Feed Intake	QT % in Offered Diet on QT % in Selected Diet
	------------------(g mbw kg^{-1} day^{-1})-----------------	
F-value	0.49	612.8
P-value	0.50	**<0.0001**
R^2	0.04	0.98
Equation	n/a	Y=0.003+0.005x
RMSE	25.40	0.0042

Table 2.8. Diet selection, weight gain, and forage digestibility's of white-tailed deer offered 3 restricted choice diets supplemented with quebracho tannin (QT) in April 2004.

Factor	DM Digest. (SE)	Protein Digest (SE)	DMI (SE)	QT Intake (SE)	Weight Gain (Se)
	---------------(%)-------------		------------------(g $\cdot$ mbw kg^{-1} day^{-1})---------------		
F value	8.82	3.05	33.14	37.67	
Model	**0.008**	**0.097**	**<0.0001**	**<0.0001**	**0.04**
Treatment					
Low CT	27.0 (2.5) b[z]	46.7 (2.8)a	95.8 (5.7) a	0.34 (0.34) b	2.1 (4.2) a
Med CT	42.0 (2.5) a	42.4 (2.8)ab	58.8 (5.7) b	3.72 (0.34) a	-3.57 (4.2) a
HighCT	35.7 (2.5) a	37.1 (2.8)b	30.5(5.7) c	4.64 (0.34) a	-17.1 (4.8)b

[z] Means in columns with different letters are significantly different $p<0.05$.

Table 2.9. Urine chemistry responses of white-tailed deer offered 3 restricted choice diets containing different levels of quebracho tannins.

Factor	**Potassium: Creatinine** micromole/L:micromole/L	**Urea: Creatinine** mmol/l:micormol/L	**Cortisol: Creatinine** nanomol/L:micormol/L
F-value	2.56	24.29	0.10
P-value	0.25	**0.04**	0.78
Treatment			
Low	0.0459 (0.0076)	0.0357 (0.0036)a	0.0096 (0.0038)
High	0.0286(0.0076)	0.0107 (0.0036)b	0.0079 (0.0038)

[z] Means in columns with different letters are significantly different $p<0.05$.

Table 2.10. Effect of quebracho tannin (QT) concentration in restricted choice diets of white-tailed deer, on dry matter intake, tannin intake, dry matter digestibility, protein digestibility, and weight gain.

Factor	**DM Digest. (SE)**	**Protein Digest. (SE)**	**Dry Matter Feed Intake (SE)**	**Weight Gain (SE)**	**QT Intake (SE)**
	---------------(%)-----------		-----------------(g kg mbw^{-1} day^{-1})--------------		
F-value	8.8	6.8	56.41	10.2	43.2
P-value	**0.008**	**0.02**	**<0.0001**	**<0.01**	**<0.0001**
R^2	0.66	0.40	0.85	0.53	0.91
Equation	$y=25.62+3.98x-0.218x^2$	$Y=46.75-0.65x$	$Y=93.18-4.32x$	$Y=3.35-1.30x$	$Y=0.070+0.78x-0.032x^2$
RMSE	7.63	5.23	12.11	7.93	0.69

Table 2.11. Effect of quebracho tannin (QT) % in selected diet on white-tailed deer urinary chemistry, including potassium, urea, and cortisol ratios with creatinine.

Factor	**Urea: Creatinine**	**Urea: Creatinine**	**Cortisol: Creatinine**
F-value	24.3	2.56	0.10
P-value	**0.04**	0.25	0.78
R^2	0.92	0.56	0.05
Equation	Urea:creatinine=0.0363-0.0017QT %	n/a	n/a
RMSE	0.0051		

Table 2.12 Spring Compensatory Gain trial analysis of variance results and LSmeans (SE) responses in the feed selection and weight gain of white-tailed deer offered one of 3 quebracho tannin (QT) dietary levels under free choice conditions.

Factor	**Dry Matter Feed Intake (SE)**	**QT % in Diet Selected (SE)**	**Total QT Intake (SE)**	**Weight Gain (SE)**
	(g·kg mbw^{-1}·day^{1})	----(%)--	-----(g·mbw·kg^{-1}·day^{-1})---	
F-value	2.15	107.98	79.0	4.46
P-value	0.17	**<0.0001**	**<0.0001**	**0.045**
Treatment				
Low CT	169.5 (7.8)	0.36 (0.16)b[z]	0.61 (0.3)b	11.82 (1.2)a
Medium CT	154.0 (7.8)	2.99 (0.16)a	4.59 (0.3)a	6.59 (1.2)b
High CT	147.2 (7.8)	3.41 (0.16)a	5.03 (0.3)a	9.69 (1.2)b

[z] Means in columns with different letters are significantly different $p<0.05$

Table 2.13. Summary results for the Spring Compensatory Gain trial evaluating the effect of % quebracho tannin (QT) in white-tailed deer selected diets on deer dry matter feed intake, total QT intake, and weight gain. Also shown is the effect of QT % in offered diets on selected diet, the effect of total QT intake on deer weight gain, and the effect of initial metabolic body weight (MBW) on compensatory weight gain.

Factor	**QT % in Diet Offered vs Selected Diet (SE)**	**Dry Matter Intake Feed vs % QT in Diet Selected (SE)**	**Total QT Intake and % Tannin in Selected Diet (SE)**	**Weight Gain and % QT in Selected Diet (SE)**	**Weight Gain and Total QT Intake (SE)**	**Compensatory Weight Gain and MBW (SE)**
	--------(%)-------	------------------------------------	(g kg mbw^{-1} day^{-1})	----------------------------		
F-value	107.98	4.12	78.99	3.58	3.96	0.55
P-value	**<0.0001**	**0.069**	**<0.0001**	**0.088**	**0.075**	0.48
R^2	0.96	0.2920	0.946	0.264	0.284	0.0519
Equation	$Y=0.141+0.618x -0.027x^2$	$Y=171.4 -6.44x$	$Y=0.28+0.94x -0.042 x^2$	$Y=11.92 -1.13x$	$Y=12.07 -0.79x$	Wt Change=19.92-0.645 mbw kg
RMSE	0.3181	15.12	0.5483	2.857	2.818	3.242

2.9. Figures

```
Sun Cured Alfalfa pellets - Control  1000.00 20/01/04   18
     Code    Ingredient Name                     Amount   Pct
     -------- ---------------------------------- ------------ ------
       02610 ALFALFA SUN-CURED                       1,000.0 100.00
     No.     Nutrient Name        Units       Actual   Dry Matter
     -------- ------------------- -------- ------------ ------------
         2 Dry Matter          %              90.00      90.00
         3 Crude Protein        %             15.00      16.67
        13 Crude Fibre         %              23.40      26.00
        14 ADF               %               31.50      35.00
        15 NDF               %               41.40      46.00
        16 RUP:Prot                            0.18       0.18
        17 RDP:Prot                           0.82       0.82
        21 Crude Fat          %               2.30       2.56
        36 DE (Ruminant)        Mcal/kg    2.38       2.64
        37 NE (m) (Ruminant)    Mcal/kg 1.12        1.24
        40 TDN               %               54.00      60.00
       113 Calcium            %              1.20       1.33
       114 Phosphorous          %             0.21       0.23
       117 Ca:P ratio                          5.71       5.71
       121 Sodium             %              0.07       0.08
       122 Potassium           %             1.40       1.56
       123 Chlorine           %              0.01       0.01
       124 Na+K-Cl-S          Meq/100g 22.95      25.50
       125 Magnesium           %             0.24       0.27
       126 Sulphur            %              0.25       0.28
```

Figure 2.1. Champion Feeds Sun-cured Alfalfa pellet Formulation Nutritional Analysis for Low tannin diet.

Sun Cured Alfalfa Pellets - **Trt1 8%**

Code	Ingredient Name	Amount	Pct
02400	SOYABEAN MEAL	57.0	5.700
02610	ALFALFA SUN-CURED	811.0	81.100
03103	Soya Oil	12.0	1.200
05805.1	Uof A Tannin 60%	120.0	12.000

No.	Nutrient Name	Units	Actual	Dry Matter
2	Dry Matter	%	90.23	90.23
3	Crude Protein	%	15.01	16.63
13	Crude Fibre	%	20.54	22.76
14	ADF	%	28.46	31.54
15	NDF	%	38.40	42.56
16	RUP:Prot		0.22	0.22
17	RDP:Prot		0.78	0.78
21	Crude Fat	%	3.13	3.47
36	DE (Ruminant)	Mcal/kg	2.36	2.61
37	NE (m) (Ruminant)	Mcal/kg	1.12	1.25
40	TDN	%	53.57	59.37
111	Tannin	%	7.20	7.98
112	Ash	%	0.02	0.02
113	Calcium	%	1.08	1.20
114	Phosphorous	%	0.21	0.23
117	Ca:P ratio		5.13	5.13
120	Salt	%	0.00	0.00
121	Sodium	%	0.06	0.06
122	Potassium	%	1.27	1.41
123	Chlorine	%	0.01	0.01
124	Na+K-Cl-S	Meq/100g	20.58	22.81
125	Magnesium	%	0.22	0.24
126	Sulphur	%	0.22	0.24

Figure 2.2. Champion Feeds Sun-cured Alfalfa pellet Formulation Nutritional Analysis for Medium tannin diet

```
Sun Cured Alfalfa Pellets - Trt2 16%  1000.00 26/01/04    13

   Code    Ingredient Name                     Amount    Pct
   -------- ---------------------------------- ------------ ------
     02400 SOYABEAN MEAL                          118.0 11.800
     02610 ALFALFA SUN-CURED                        611.0 61.100
     03103 Soya Oil                         30.0  3.000
   05805.1  Uof A Tannin 60%                    241.0 24.100

   No.     Nutrient Name      Units       Actual   Dry Matter
   -------- ------------------ -------- ------------ ------------
        2 Dry Matter        %              90.51      90.51
        3 Crude Protein      %             15.05      16.62
       13 Crude Fibre        %             17.45      19.28
       14 ADF              %               25.13      27.76
       15 NDF              %               35.03      38.70
       16 RUP:Prot                         0.25       0.25
       17 RDP:Prot                         0.75       0.75
       21 Crude Fat         %              4.54       5.02
       36 DE (Ruminant)       Mcal/kg      2.37       2.62
       37 NE (m) (Ruminant)    Mcal/kg 1.15          1.27
       40 TDN              %               53.89      59.54
      111 Tannin            %              14.46      15.98
      112 Ash             %                0.04       0.04
      113 Calcium           %              0.95       1.05
      114 Phosphorous          %           0.21       0.23
      117 Ca:P ratio                       4.49       4.49
      120 Salt            %               0.00       0.01
      121 Sodium            %             0.05       0.05
      122 Potassium          %            1.13       1.25
      123 Chlorine          %             0.01       0.02
      124 Na+K-Cl-S         Meq/100g 18.10          20.00
      125 Magnesium          %            0.20       0.22
      126 Sulphur           %             0.19       0.21
```

Figure 2.3. Champion Feeds Sun-cured Alfalfa pellet Formulation Nutritional Analysis for High tannin diet.

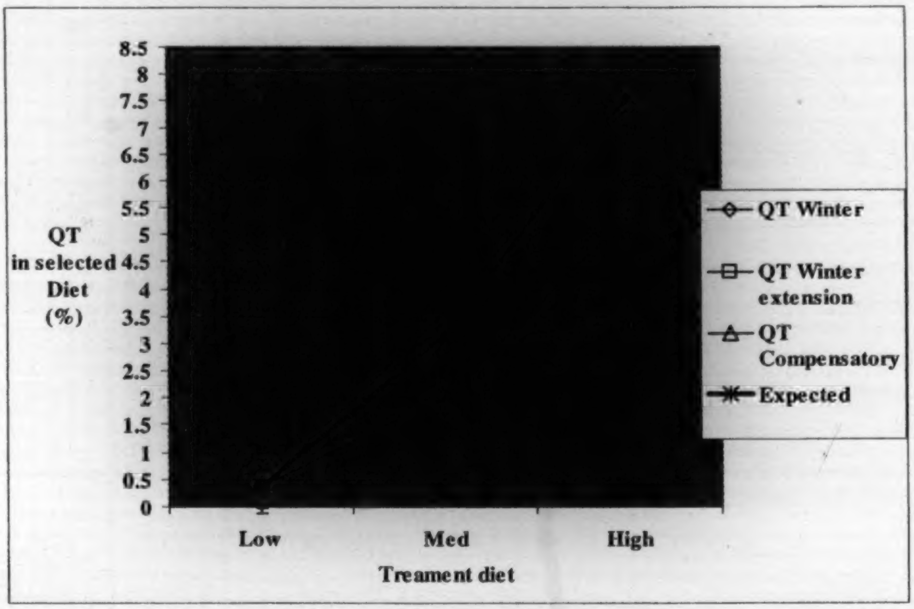

Figure 2.4. White-tailed deer quebracho tannin (QT) concentrations in selected diets versus that available in feed offered, as well as expected levels under random foraging, in each of the Winter Pasture, Winter Extension, and Compensatory Gain trials.

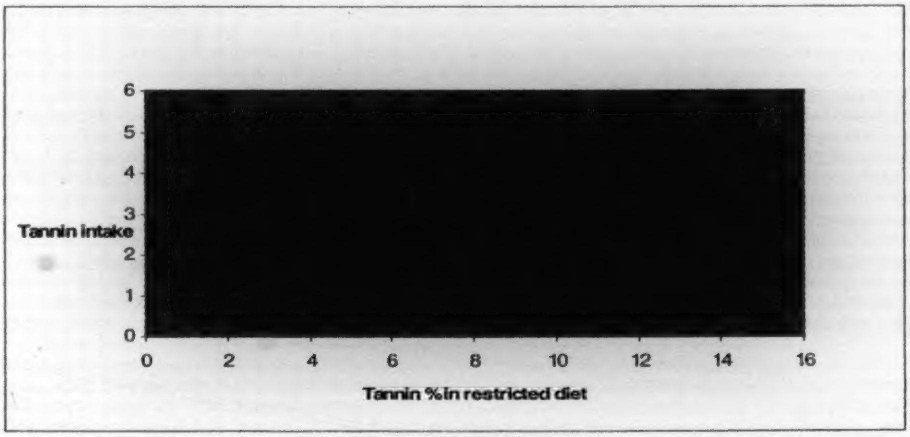

Figure 2.5. Relationship between quebracho tannin (QT) actual intakes (g·kg mbw^{-1}·day^{-1}) by white-tailed deer across three dietary concentrations (%) of QT during the Digestibility Trial of 2004 (all replicates).

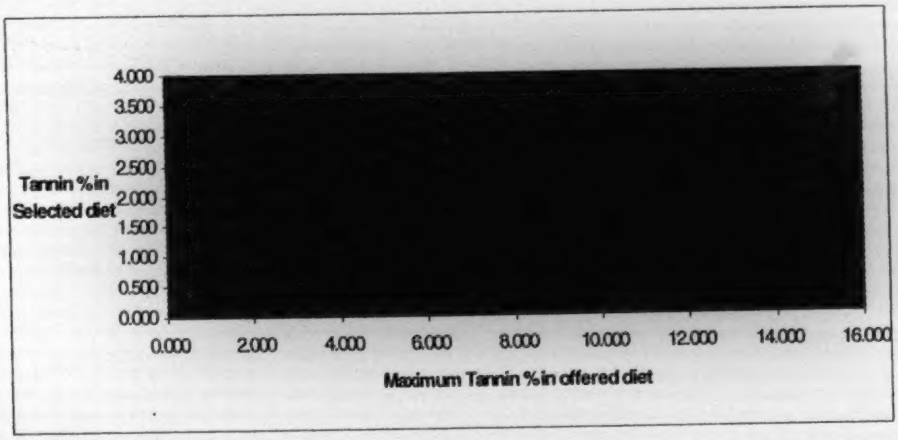

Figure 2.6. Relationship of quebracho tannin (QT) intake (% of diet) in white-tailed deer across maximum concentrations of QT offered in diets during the Compensatory Gain Trial of 2004 (all replicates).

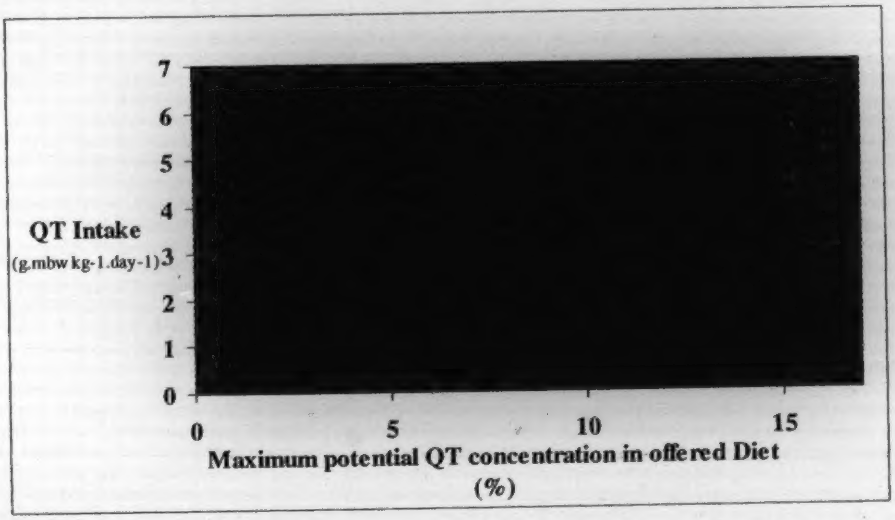

Figure 2.7. Actual quebracho tannin (QT) intakes (g kg mbw^{-1}·day^{-1}) compared to the maximum QT concentration possible within diets offered to white-tailed deer (%) within the Compensatory Gain Trial of 2004 (all replicates).

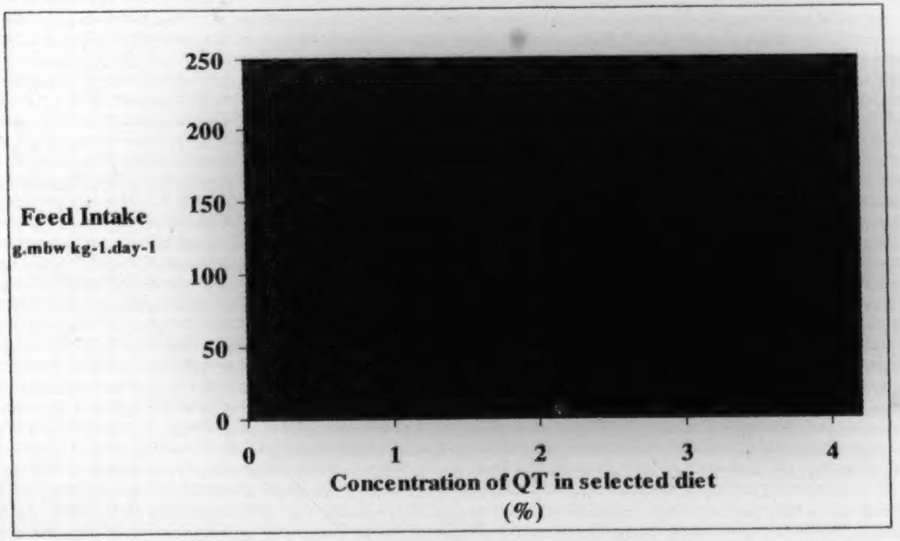

Figure 2.8. Effect of quebracho tannin (QT) concentration (%) in selected deer diets on dry matter feed intake (g· mbw kg^{-1}·day^{-1}) of white-tailed deer offered 3 diets during the Compensatory Gain Trial 2004 (all replicates).

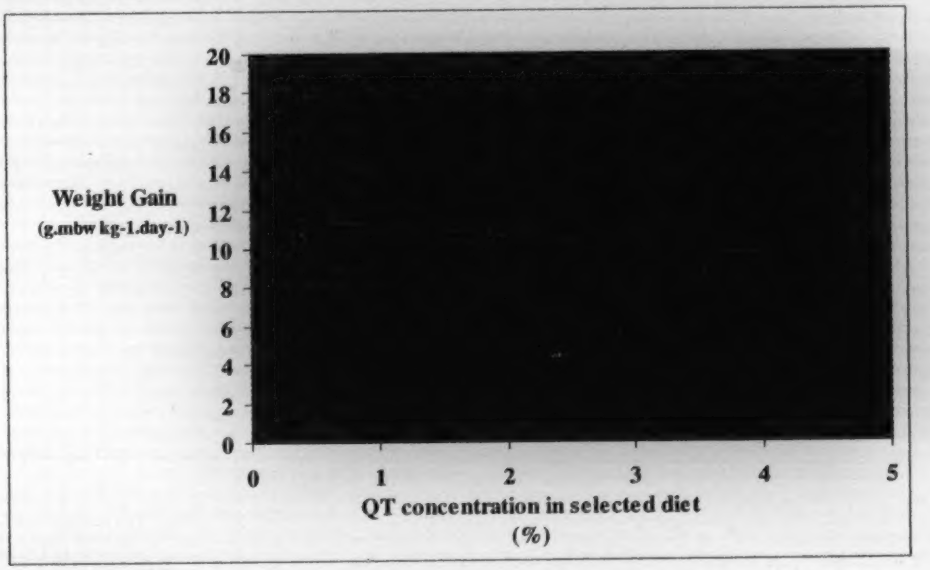

Figure 2.9. Effect of quebracho tannin (QT) concentration (%) in selected diets on the weight gain (g· mbw kg^{-1}·day^{-1}) of white-tailed deer during the Compensatory Gain Trial 2004 (all replicates).

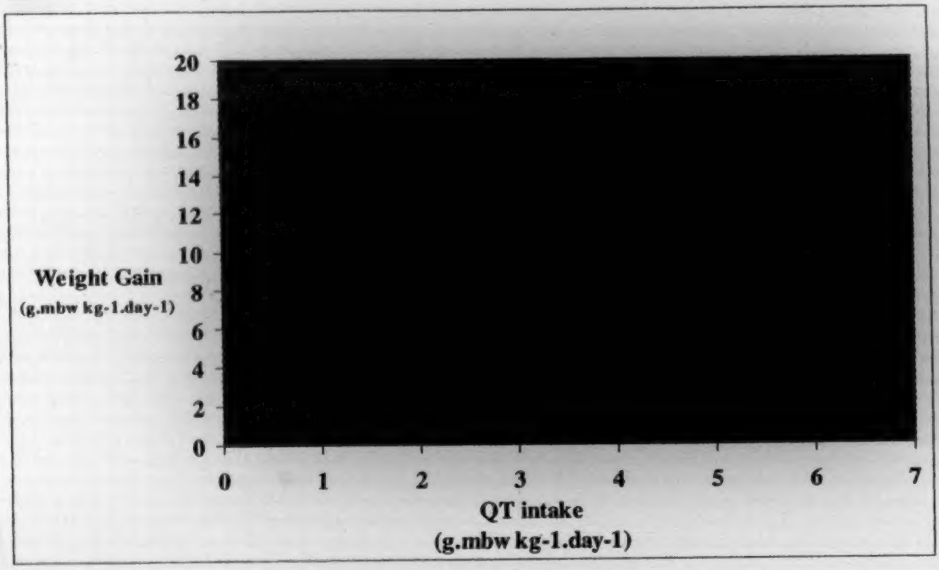

Figure 2.10. Effect of quebracho (QT) tannin intake (g mbw kg^{-1} day^{-1}) on the weight gain (g mbw kg^{-1} day^{-1}) of white-tailed deer during Compensatory Gain Trial 2004 (all replicates).

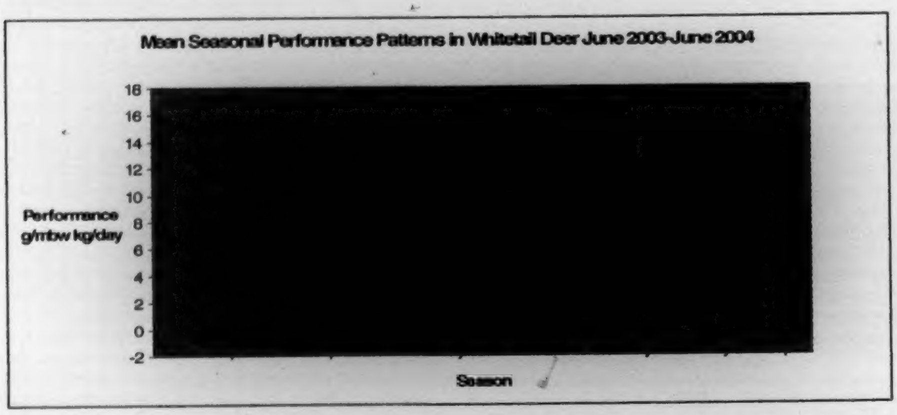

Figure 2.11. Seasonal rates of weight gain (g mbw kg^{-1} day^{-1}) by white-tailed deer offered the control diet of 15% protein sun-cured alfalfa (*Medicago sativa*) pellets between 17 June and 8 Sept 8, 2003, and 3 February and 7 June, 2004 with data from the Summer Pasture, Winter Pasture, Digestibility, and Compensatory Gain Trials.

3.0 Chapter 3 Suitability of Chicory, Birdsfoot Trefoil, and Alfalfa as Pasture for White-tailed Deer in Alberta, Canada

3.1. Introduction

Interest in deer farming worldwide has increased in the last 30 years due to Asian and European demand for high quality antler velvet and venison products. Recent demand for quality white-tailed deer (WTD) (*Odocoileus virginianus*), trophy hunting opportunities and to a lesser extent venison has resulted in a keen interest in their production in North America (Telfer and Scotter, 1975; Alsager and Alsager, 1984; Twiss et al., 1996).

Canadian deer production has rapidly increased at an annual rate of 44% from 1991-1999 and in 2001 there was 53 258 deer comprising fallow deer (*Dama dama*), WTD, mule deer (*Odocoileus hemionus*), and red deer (*Cervus elaphus*) (Statistics Canada 2001) As of the 2006, deer numbers in Canada had declined slightly to 46 748, and within the provinces of Alberta and Saskatchewan there were 17 546 deer on 238 farms, comprised primarily of WTD, and to a much lesser extent, fallow and mule deer (Statistics Canada 2006).

This decline can be attributed to breeding stock prices which stabilized in 2002 so the industry must now direct attention to reducing production costs as feed costs can account for 65% of livestock production expenses (Beranek, 2006). Furthermore, game farming systems in seasonal environments of Canada depend heavily of expensive supplements to meet nutritional needs and maximize deer performance and with high production and slaughter costs relative to carcass size and value; venison production offers marginal profits (Hudson et al. 2000). This is more critical for deer than elk as WTD do not make efficient use of grass pastures (Hudson et al. 2000). Provision of supplemental feeds however, is a more expensive feeding alternative to the provision of pasture capable of meeting deer requirements. Evaluating forage suitability for deer has therefore become a priority in aiding development of the deer farming industry in western Canada (Alberta Agriculture 2003), with the primary areas of improvement being reduced production costs, increased feeding efficiency, and environmental sustainability (Aerts et al., 1999).

Schreurs et al. (2002) identified benefits of pasture forages containing condensed tannins (CT). At moderate concentrations (i.e. 2-4%) dietary CT have improved animal performance, reduced nitrogen excretion, prevented bloat (Tanner et al., 1995), and reduced dependence on anthelmintics (Aerts et al. 1999). CT have also improved the production efficiency of lactation, wool yield, and live weight gains in sheep (Aerts et al., 1999; Min et al., 1998), milk quality and productivity (Roy et al., 2004; Barry and McNabb 1999), meat flavor (Schreurs et al., 2004), and ovulation rate (Terrill et al., 1992; Wang et al., 1996[a], 1996[b]). In Odocoileinae deer, Hudson et al. (2000) found that dry matter intakes increase with the inclusion of purified bark tannins at levels up to 10% of the diet. Considerable research has been conducted on the known anti-nutritive effects of tannins on domestic livestock (Disler et al.1975; Sandusky et al., 1977; Roy and Mukherji 1979; Jones and Hunt 1983; Panda et al., 1983; Van Hoven, 1984; Barry, 1985; Mehansho et al., 1987) and understanding how wild ruminants are able to tolerate tanniferous diets, with CT tolerance decreases among ruminant species in the following order: deer > goat > sheep > cattle (Hudson et al. 2000; Kumar and Singh 1984; Robbins et al., 1987[a]; Robbins et al. 1987[b]).

To date, little research has been conducted on the performance and preference of white-tailed deer grazing tannin-rich forages. The evaluation of novel forages for livestock involves the assessment of forage establishment and over-winter survival, as well as agronomic characteristics. Successful establishment of forage includes weed competitive ability with persistence over several growing seasons necessary to reduce pasture rejuvenation costs. Agronomic attributes of particular interest to livestock producers include biomass availability and quality (protein, digestibility, and in the case of deer, tannins) throughout the growing season. Finally, the ultimate measure of forage suitability for deer production is the preference deer express for these forages, together with their weight gain while grazing them.

Many shrub and tree foliages are likely to be higher in tannins than pasture plants (Leng, 1997) Given the potential importance of tannins in deer diets, their presence in natural deer diets, and that most agronomic forages contain low tannin levels, novel forages greater in tannin content require further testing using deer, particularly in western Canada. This trial compared the suitability of two alternative forages, including birdsfoot trefoil (trefoil) (*Lotus corniculatus* L cv 'Leo'), and chicory (*Chiocorium intybus* L. cv 'Puna), with alfalfa (*Medicago sativa* L. cv. "Rangelander') for use as deer pasture in northern Alberta.

Alfalfa is the conventional forage widely used in western Canada, including in deer pastures. Although considered highly adapted to Alberta's climate, this forage is low in condensed tannins (Mould and Robbins, 1982), and contains saponins that reduce rumen motility (Lindahl et al., 1957; Klita et al., 1996; reviewed Sen et al., 1998; Francis et al., 2002). Trefoil is also grown in Alberta, but to date has had limited use compared to alfalfa, and has been identified in recent studies to improve red deer dry matter intake and weight gain (Adu et al., 1998). In contrast, chicory is new in Canada and was developed in New Zealand for their extensive deer farming industry (Moloney and Milne 1993). Puna chicory is a perennial herb, while other varieties are biennial (Baert 1997), that grows as a rosette, has broad leaves and a long thick taproot that has been bred for multiple industrial uses (Labreveux 2002), with excellent forage qualities have being developed for pasture purposes (Lancashire, 1978). Recent studies in red deer have shown increased dry matter intakes and weight gains while grazing chicory (Kusmartono and Barry 1997; Kusmartono et al., 1996), and WTD have exhibited a preference for chicory (Foster et al. 2002). Chicory is now grown throughout much of the United States and may be valuable alternative deer forage in Alberta.

The specific objectives of this study were to:

1. Compare the establishment and over-winter survival of chicory to birdsfoot trefoil and alfalfa in two growing seasons.
2. Determine agronomic characteristics of the 3 forages including:
   a. Seasonal biomass production
   b. Crude protein concentration and yields.
   c. Neutral detergent fiber concentrations and neutral detergent soluble yield.
   d. Condensed Tannin Concentration

3. Determine dietary preferences of white-tailed deer for each of these 3 forages when given a choice.
4. Evaluate deer performance (i.e. weight gain) while grazing pasture seeded to each species.

3.2. Materials and Methods

This study involved the evaluation of key agronomic traits of 3 forages and seasonal changes in production and quality during the summers of 2003 and 2004 utilizing a randomized complete block design (7 blocks). Pens and plots were arranged in a manner that permitted 6 pens to be used in a deer grazing performance trial and 1 matrix pen which was used to evaluate deer preference by means of observation and forage removal with all trials involving a total of 58 WTD.

3.2.1. Site Description

This research was conducted at the Alberta's Best Deer Group Ltd. game farm in the Lower Boreal Mixedwood region of north central Alberta, 11 km east of the town of Athabasca (54° 42' 8.7"N; 113° 05'31.7" W; elevation 575m asl). The farm consists of two quarter sections (512 ha) of land, fenced and cross fenced with 2.43m tall high tensile page wire. It was equipped with a large, well-designed handling and urine collection facility including many indoor and outdoor pens, and paddocks. Prior to this research, the farm was utilized for WTD pasture and hay production, typically with forage stands consisting of alfalfa, smooth brome (*Bromus inermis* Leyess), quackgrass (*Agropyron repens* L), and alsike clover (*Trifolium hybridum* L). The farm's deer herd consisted of all ages of bucks and does, with the herd numbering about 800 deer.

The dominant landform of the area was a mix of level organic muskeg flats combined with localized high relief landforms up to 4% in slope. The predominant soil type was an Orthic Gray Luvisol of the La Corey, Plamondon and Spedden series (Alberta Soil Information Center 2001) on medium textured loam and clay loam till, with poorly drained Organic soils in lowlands. The 30-year mean annual precipitation for the Athabasca region is 503.7 mm, with 381.7 mm of rainfall and

122 mm of moisture as snow. Tables 3.1 and 3.2 provide detailed climatic data from 2003-2005 in relation to the long-term averages.

3.2.2. Experimental Design

Three forages including alfalfa (*Medicago sativa* L. cv. 'Rangelander'), chicory (*Chiocorium intybus* L. cv 'Puna'), and birdsfoot trefoil (*Lotus corniculatus* L cv 'Leo'), were established on each of 7 pasture plots in a randomized complete block design. Plots within two of the seven blocks averaged 0.75 ha (Table 3.3), whereas plots in the other 5 blocks were much smaller, averaging 169 m^2. Larger plots were individually fenced to facilitate evaluation of deer performance on pastures seeded to a single species. Five smaller blocks were fenced within a single pen to permit measurements of deer foraging behaviour and resource selection preference across the resulting forage matrix. Following seeding and successful establishment of forages in 2004, each of the 7 paddocks (2 chicory, 2 alfalfa, 2 birdsfoot trefoil, and the matrix) were individually fenced with 2.7m high page wire, with gates available to facilitate handling and weighing. Animal use protocols were approved by the faculty animal care committee as in compliance with guidelines of the Canadian Council on Animal Care.

3.2.3. Forage Seeding

Seed bed preparation in 2003 involved spray application of glyphosate herbicide on 25 May at a rate of 4.8 L/ha. Seven days later on 7 June, 2003, sites were disced several times and then seeded with a 3-m wide Brillion forage seeder. Seeding in 2003 was delayed due to an unusually cold spring. After seeding, one pass with harrows was used to ensure good seed to soil contact.

Due to complications with forage establishment across a portion of some plots in 2003, plots were reseeded on 20 May, 2004. Seeding was accomplished in the same manner as in 2003 except no glyphosate herbicide was applied. In both years, seeding rates were 11.4, 12.3 and 8.9 $kg \cdot ha^{-1}$ for alfalfa, birdsfoot trefoil and chicory, respectively. A global positioning system was used to measure final plot sizes. Chicory seed was neither inoculated nor fertilized and had a germination rate of 83%. Both alfalfa and birdsfoot trefoil were inoculated with Noducoat^{TM} at three times the recommended rate, and coated with a phosphate fertilizer, which protects the rhizobia inoculant and keeps it viable for six months, accounting for 33% of seed weight. Germination rates for the alfalfa and birdsfoot trefoil were 97% and 79%, respectively.

3.2.4. Forage Evaluation Trial

All seven blocks were used to evaluate forage establishment, productivity and quality in each of 2003 and 2004, as well as the over winter survival of forage seeded the first year. Forage productivity and quality were sampled on 12 August 2003. In 2004, however, repeated measurements of forage productivity were conducted at 3 times throughout the growing season, including 25 July (n=7), 1 August (n=5; resource selection blocks only), and 19 September (n=7). Two blocks (#1 and #2 in Table 3.3) were not sampled in August to minimize handling stress on deer using these pens for the grazing performance trial ongoing at the time. Data were collected by sampling four, 0.5 x 1.0 m quadrats randomly located on a 20 m transect within each of the 6 larger plots (i.e. pens), and on a 10 m transect in each of the 15 smaller matrix plots (Fig. 3.1).

3.2.5. Forage Establishment and Agronomics

Forage establishment was assessed along the sampling transects. On each transect quadrats were sampled for: average sward height (8 sub-samples per quadrat), estimated foliar ground cover (%) of each plant species, and seeded plant density (plants m^{-2}). In addition, the biomass (kg ha^{-1}) of seeded forage, volunteer clover (which emerged from the soil seed bank) and weed components were assessed by harvesting all vegetation to 2-cm height within four, 0.5 m^2 quadrats along each transect. Samples were harvested, sorted to vegetation group, dried at 60°C to constant mass, and weighed.

All initial measures were taken 66 days post seeding in both 2003 and 2004, corresponding to 12 August, 2003, and 25 July, 2004. During 2004, biomass was sampled 2 additional times in August and September to determine differences in the seasonal availability of the different forages.

Forage quality was assessed on all the seeded forage samples collected in each year, including all 3 times during 2004. Each sample was ground to pass a 1-mm screen using a Wiley Mill. Forage nitrogen (N) levels of the different forages were assessed using a LECO FP-528 nitrogen auto-analyzer (AOAC 1995), with N values converted to % crude protein using a conversion index of 6.25. Crude protein concentration and biomass values were subsequently combined to determine the crude protein yield (CPY) of each forage component as well (i.e. CPY= biomass x CP concentration/100).

Both neutral detergent fibre (NDF) and acid detergent fiber (ADF) were determined using the Ankom filter bag technique (Ankom Technology Corporation 2005abc). NDF provides a more conservative estimate of forage digestibility, which is more appropriate for deer (Robbins et al. 1975) thus, only NDF values are presented here. The latter were also used to derive neutral detergent soluble values (i.e. 100 – NDF %= NDS %), which in turn, were used to calculate neutral detergent soluble yield (NDSY) values using the same approach as for crude protein yield.

CT levels were determined by the Agriculture and Agri-Food Canada-Lethbridge Research Center using reversed-phase high-performance liquid chromatography (Koupai-Abyazani et al. 1992). Two randomly chosen samples of the 4 samples harvested from each plot were analysed for tannin content.

The over-winter survival of forages seeded in 2003 was assessed on 17 May, 2004. Within each plot, four randomly placed, 0.5 m x 1.0 m quadrats were sampled on each transect. Due to problems with initial establishment of seeded forages in spring 2003, only six plots were available for sampling of alfalfa (seven plots for each of chicory and birdsfoot). Within each quadrat, ocular estimates were made of live and dead foliar cover (%) of each forage, as well as the density of both live and dead forage plants (stems m^{-2}).

3.2.6. Grazing Performance of White-tailed deer

From 30 July to 19 September, 2004, the two large pens seeded to each forage type were stocked with a minimum of 6 white-tailed bucks. Additional does were stocked in an attempt to equilibrate grazing pressure among pens based on differences in individual pen sizes and initial differences in seeded forage productivity on 25 July (Table 3.4). Grazing pressure is the ratio of forage demand to forage supply on day 1 of the trial (Heitschmidt and Taylor 1991). Deer grazing pressure was expressed as a percent and calculated as the daily forage demand of all deer within a pen, assuming an expected 4% of body weight dry matter feed intake (kg day^{-1}), divided by the total forage available ($kg \cdot pen^{-1}$).

Grazing pressures were similar in alfalfa and chicory pens, whereas grazing pressure was invariably greater in birdsfoot trefoil as a result of the need to stock all paddocks with a minimum of 6 bucks to obtain measures of weight gain. Equal grazing pressures based on seeded forage allowance alone would have precluded the grazing trial due to low levels of birdsfoot trefoil production and an expected need for a 50 day grazing trial to measure weight gains. Consequently, total forage and clover production was used to equilibrate grazing pressures with an expected average deer weight of 67kg. During weighing, it was necessary to move animals to smaller pens to minimize stress. Deer stocking rates were also adjusted to accommodate an actual average deer weight of 50kg. Grazing pressures of total forage and clover were very similar, ranging from 0.8-1.5% across all pens (Table 3.4). Although forage availability was expected to increase due to forage growth, forage availability was monitored to determine if the trial should be terminated early should seeded forage become limiting.

Weight gain was calculated as the difference between initial body weight (day 0) and final body weight (day 50) and expressed as ($g \cdot kg\ mbw^{-1} \cdot day^{-1}$). Utilization was assessed separately for weeds, volunteer clover and the seeded forage within each pen by placing 3, 1.5 m x 1.5 m portable grazing cages in each paddock, and harvesting all biomass both inside and outside each cage within a 0.5 m x 1.0 m quadrat. All plant material was separated to forage and vegetation types, dried at 60°C to constant mass, and weighed.

3.2.7. Resource Selection by White-tailed Deer

The single paddock containing the matrix of smaller plots of forages was stocked with six adult white-tailed bucks from 31 July to 17 August, 2004, to determine the time spent grazing in each forage type and to quantify actual forage removals.

3.2.7.1 Forage Removal

Forage removal was assessed using two range cages, 1.5m x 1.5m, randomly placed within each of the 15 matrix plots. Each range cage was sampled as in the performance trial, with the exception that the size of harvested quadrats was reduced to 0.5 m x 0.5 m (0.25 m^2) to allow re-sampling of forage productivity under the same cages on 19 September (i.e. the final sampling date for total biomass productivity).

To determine forage preferences by deer, caged and uncaged biomass values were compared to calculate the removal of biomass of seeded forage, volunteer clover and weeds within each plot. In addition, the above data were used to determine a relative preference index for each seeded forage species. In each pasture, the mean biomass for each forage class including; alfalfa, birdsfoot trefoil, chicory, alsike clover, and other plants (categorized as weeds), was assessed. Using these values, 3 indices of utilization were calculated for all forage classes within each block. These indices included total forage removal, % use of each forage, and a relative preference index (RPI). An RPI compares relative use to relative availability: use of forage in a greater or lesser proportion to that available indicates forage preference and avoidance, respectively (Moisey 2003).

RPI = (% of total forage use -% of total available forage)/(% of total use+% of total available forage)

3.2.7.2. Foraging Behaviour

Feeding time is another measure of foraging preference. Observational data were collected on the foraging behavior of each individual deer grazing within the matrix. During the 17 day trial 6 deer were observed with high power binoculars from an elevated stand, morning and evening for a period of up to 2 hours. During this time, positional data were collected on each deer during foraging events in 5 minute intervals for a minimum of 10, and up to 20 observations per deer (Jacobsen and Wiggins 1982). Data recorded included whether the deer was in chicory, alfalfa or birdsfoot trefoil plots when actually feeding. Individual deer were identified through the use of large numbered ear tags. If a deer was not actively feeding at the end of five minutes, it was omitted from the scan. Daily estimates of deer visitation to each forage type were pooled during the early (day 1-5), mid (day 6-10) and late (day 11-17) periods of the trial, with no data being collected on days 2, 12, 13, 15, and 16. Preferences for alfalfa, birdsfoot trefoil, and chicory were estimates during each period.

3.3. Data Analysis

Data were analyzed with Statistical Analysis Software (SAS) systems edition 9.1 (SAS 2002). Prior to analysis all data were checked for normality through examination of the residuals. Measured response variables in this study included forage establishment (plant density, cover, height and survival), agronomic characteristics (biomass, crude protein, CPY, NDF, and NDSY, tannins), and deer foraging responses (weight gain, utilization and foraging time). All data were analyzed using an analysis of variance (ANOVA) with Proc Mixed (SAS 2002), where seeded forage type, year of establishment, and date of sampling were fixed factors, and forage seeding blocks considered random. Where significant main effects or interactions were found, post-hoc comparisons of lsmeans were performed using the Tukey's method (Steel and Torrie 1980), with differences considered significant at $p<0.05$, unless otherwise indicated.

Repeated measures analysis was utilized in the assessment of deer foraging time, as well as in the assessment of seasonal changes in forage agronomic characteristics during 2004. During repeated analysis, individual deer and forage plot were considered the subjects. Linear and polynomial regression analysis was utilized to assess whether tannin concentration in the selected diet had an effect on forage preference and/or associated weight gain in the deer resource selection and grazing performance trials, respectively. Proc mixed and Akaike's minimum information criteria scores (Burnham and Anderson 1998; Gagne and Dayton 2007) were used to determine best fit linear and polynomial regression models.

3.4 Results

3.4.1. Growing Conditions

Climate data was obtained through a local weather station maintained by Environment Canada (Environment Canada 2007) over the study period (Table 3.2). Mean monthly temperatures were not markedly different from the long term average (Table 3.1), with the exception of May 2003 that was much cooler. Depth to frost was within 30 cm of the soil surface in early June of that year, which delayed cultivation and seeding in the area. Although growing season (April to August) precipitation did not differ substantially between 2003 and 2004 (300 and 318 mm of moisture in 2003 and 2004, respectively), both years were slightly below the 332 mm average for the region. Moisture was also variable within each year, however, with most months below average in moisture during 2003 with the exception of June, which was very wet (Table 3.1). One year later in 2004, May and July were relatively moist, with April and June being dryer than the norm.

3.4.2. Forage Establishment

Forage suitability evaluations for deer pasture in northern Alberta in 2003 and 2004 revealed that forage height, cover and biomass were effected by forage type ($p<0.001$), year of seeding ($p<0.05$), and interactions between forage type and year ($p<0.01$) (Table 3.5). Alfalfa consistently produced the tallest forage, reaching a mean height of 35cm during the year of establishment, with birdsfoot trefoil being the lowest (Table 3.6). Although alfalfa tended to be greater in height than both the other forages in either year of assessment, chicory remained similar in height to trefoil in each year (Table 3.6),

Live foliar cover in chicory averaged 76%, nearly 20% greater than alfalfa, followed by birdsfoot trefoil, which had a ground cover less than 40% (Table 3.6). While chicory remained much greater than trefoil in cover in both years of establishment, alfalfa cover responses were variable between years. During 2003, alfalfa cover was relatively low, similar to that of trefoil, while one year later alfalfa cover was much greater, similar to that of chicory (Table 3.6).

Overall, chicory productivity (1638 kg ha^{-1}) was slightly greater but statistically equivalent to alfalfa, while birdsfoot trefoil production was significantly lower than the others, producing less than half of chicory (Table 3.6). Strong differences among forages were also evident between years. In 2003, chicory out yielded both of the other species, while in 2004, poor chicory and trefoil production coupled with high alfalfa production, led to similar biomass yield between chicory and alfalfa (Table 3.6).

Forage densities varied only by year ($p<0.0001$) (Table 3.5), and were similar in all forage types within years, producing an average of 112 and 246 shoots per m^2 in 2003 and 2004, respectively. All forages generally established better during the second year of the study.

The competitiveness of the forage was assessed in 2004 through the quantification of weed biomass. Weed biomass was effected ($p=0.002$) by forage type (Table 3.5), with weed biomass greater in trefoil (2141 kg ha^{-1}) compared to stands seeded to either alfalfa or chicory, by 2 to 3.3 times, respectively. Volunteer clover biomass was also compared following establishment in 2004 (Table 3.8), with similar levels among all 3 forages ($p=0.07$) (Table 3.6). Clover biomass was approximately 590 kg ha^{-1}.

Forage quality at establishment (i.e. 69 days post seeding) revealed that crude protein levels were effected only by forage type ($p<0.001$) (Table 3.5), with alfalfa having at least a 5% greater protein concentration than the other forages (Table 3.6). The neutral detergent soluble (NDS) fraction of seeded forages were compared in 2004, and differed among forages ($p=0.03$; Table 3.5). Chicory had nearly a 6% greater NDS content compared to trefoil. Finally, condensed tannins concentrations were effected by both forage type and year of establishment ($p<0.001$) (Table 3.5). Among forages, tannin levels were nearly 6% for trefoil, which remained much greater than either of the other 2 species (Table 3.6). Although chicory had greater tannin levels than alfalfa, they remained under 1.2%.

3.4.3. Winter Survival of Perennial Forages

Further evaluation of forage suitability involved examination of over-winter survival in 2004 of the 3 forages seeded the previous year. Both live and dead foliar cover differed among forages (Table 3.7). Among forages alfalfa had the greatest live cover at 25.1 %, while trefoil and chicory remained under 2%. Dead cover (i.e. presence of plant skeletons that did not survive) followed the opposite trend (Table 3.7). Thus, although trefoil and chicory had favorable establishment the previous year, few of these plants successfully over-wintered. These results were also corroborated by the density of live and dead plants in the spring of 2004 (Table 3.7). Only 9.3% of chicory plants appeared to have survived the winter. Similarly, 1.7% of trefoil plants survived. In contrast, nearly 72% of alfalfa plants survived. Notably, total live and dead plant density remained equivalent ($p=0.60$) among all forages suggesting that they had similar establishment the previous year.

3.4.4. Seasonal Forage Productivity in 2004

Seasonal forage dynamics, including biomass and quality, were assessed only during 2004 when swards were repeatedly assessed during the growing season. Within this analysis, emphasis was placed on the presentation and interpretation of forage and forage by month effects, where present.

Seeded forage biomass was effected by forage type, month of sampling, and their interaction ($p<0.05$) (Table 3.8). Overall, alfalfa yields were greater than either of the other species, with trefoil and chicory remaining similar (Table 3.8). The interaction of forage with sampling time reflect the slow establishment of trefoil, which led to particularly low yields in July, lower than that of all other species including chicory.

Volunteer clover biomass in 2004 was effected by month of sampling ($p<0.0001$) and the forage type ($p=0.07$) seeded. Among forages, volunteer clover biomass was greatest in the trefoil and chicory forage plots, ranging from 48 to 58% greater than that of alfalfa. Total biomass levels of forage and clover remained similar among trefoil and chicory plots, but remained more than 850 kg ha^{-1} lower than that of alfalfa plots (Table 3.8). While alfalfa and clover yields rapidly increased to a maximum in August, trefoil/clover and chicory/clover yields continued to increase into September of 2004 (Table 3.8).

Weed biomass was affected only by forage type ($p<0.0001$) (Table 3.8). Weed biomass in birdsfoot trefoil plots was at least 1000 kg ha^{-1} greater than within those plots seeded to either alfalfa or chicory (Table 3.8).

3.4.5. Seasonal Changes in Forage Quality and Nutrient Yield

Forage crude protein concentrations varied by forage type and month ($p<0.05$) (Table 3.9). As expected, protein levels progressively declined through September (Table 3.9). Among forages in 2004, alfalfa had 3.5% greater crude protein levels compared to trefoil. Although chicory was intermediate in protein, it remained statistically similar to the other 2 species.

Concentrations of NDF varied by forage type, month, and the forage by month interaction ($p<0.001$) (Table 3.9). Among forages, chicory was lower in NDF overall compared to the others, by greater than 10%. Temporal variations in NDF levels were also apparent among the forages (Table 3.9). While alfalfa and trefoil had modest increases in NDF concentrations throughout the summer, chicory demonstrated an unexpected decline in NDF from July to August, with only moderate increases in September to levels that remained below those of July (Table 3.9).

Condensed tannin concentrations were effected by both forage type and month of sampling ($p<0.05$) (Table 3.9). Tannin levels were similar between alfalfa and chicory (less than 0.5%), but remained much lower than those of trefoil at 5.4% (Table 3.9). Seasonal tannin concentration trends indicated that peak tannin levels were present in August (2.35%), more a third of percent greater than in either July

(1.96%) or September (1.95%), primarily due to the high tannin levels in trefoil at that time.

Clover crude protein, NDF, and condensed tannin concentrations are reported for each forage type and month in Table 3.10. In general, clover had crude protein concentrations greater than the seeded forages, lower NDF levels, and tannin concentrations slightly greater than alfalfa and chicory, but below that of trefoil.

3.4.6. Forage Crude Protein Yield

Seeded forage crude protein yield (CPY) was effected only by forage type ($p>0.02$) (Table 3.11). Alfalfa CPY was nearly double or more of that of both chicory and trefoil. Volunteer clover crude protein yield was not affected by forage type, but was affected by month and the interaction between forage type and month of sampling ($p<0.01$) (Table 3.11). Clover crude protein yields within both alfalfa and chicory peaked early and remained relatively consistent throughout the growing season into September. In contrast, clover CPY more than doubled within trefoil plots between August and September (Table 3.11).

Combined forage and volunteer clover CPY was effected by forage type, month and the interaction of forage type and month ($p<0.07$) (Table 3.11). Total CPY levels were similar between trefoil and chicory, but remained much lower than alfalfa. Strong seasonal dynamics were also evident within each forage type. While chicory plots remained relatively stable in total CPY throughout the growing season, alfalfa plots peaked in CPY during August, and trefoil plots continued to increase in CPY into September (Table 3.11).

Forage neutral detergent soluble yield (NDSY) was effected by forage type and month ($p<0.001$) (Table 3.12). The overall forage effect on NDSY indicated alfalfa provided much greater NDSY than either trefoil or chicory. Clover NDSY was only affected by month, peaking in September, as did the combined NDSY of both seeded forage and volunteer clover (Table 3.12). Overall, the NDSY of both clover, and combined total of forage and clover, increased as the season progressed, peaking in September, with the latter ranging from 1850 to 2147 $kg \cdot ha^{-1}$ among seeded forage types.

3.4.7. Time Spent Grazing

The time deer spent foraging was affected by forage type ($p=0.02$) (Table 3.13). Based on these grazing times, deer preferred chicory (38.4% of grazing time) over alfalfa and trefoil (Table 3.13). Although no forage x sampling period interaction was present, it was noted that deer foraging times within chicory declined, particularly during the last grazing period of the trial.

3.4.8. Deer Forage Preferences

Actual forage utilization levels across the matrix did not vary significantly, despite ranging from 38 $kg\cdot ha^{-1}$ (clover) to 352 $kg\cdot ha^{-1}$ (alfalfa) (Table 3.14). Similarly, RPI values did not differ significantly despite marked apparent differences among components. RPI values were greatest for trefoil at 2.11, intermediate for chicory at 1.40, and lowest for alfalfa, weeds and volunteer clover, at values much less than 0.6 (Table 3.14). Only % utilization differed among components ($p=0.06$), with birdsfoot trefoil greater than volunteer clover. Nevertheless, utilization rankings among components were similar to those of the RPI values. Forage biomass availability within the matrix also differed among components ($p=0.02$), with weeds greater than trefoil (Table 3.14). Notably, standard errors of the means were very large in both the forage availability and utilization data (Table 3.14). Regression analysis did not identify a significant effect of condensed tannin dietary concentration on any of the three white-tailed deer preference indices, including utilization ($kg\cdot ha^{-1}$ and %) and the RPI ($p=0.55$, $p=0.188$, and $p=0.12$, respectively),

3.4.9. Deer Performance

Weight gain was affected by forage type ($p=0.06$). Weight gain was similar among deer feeding within the paddocks seeded to birdsfoot trefoil and chicory, which in turn were more than two times greater than deer feeding in paddocks seeded to alfalfa (Table 3.15). Linear regression analysis found no relationship ($p=0.12$, $R^2=0.49$, $y=5.13+0.778x$) between tannin concentrations in the seeded forage areas and associated deer weight gain however it did have a stronger relationship than those found for crude protein (p=0.30) and NDF (p=0.74).

Notably, biomass availability differed between vegetation components among the deer performance paddocks, including weeds, clover and seeded forage (p=0.02), with seeded forage and clover being nearly 3 times greater than that of weeds (Table 3.16). No differences in absolute forage removal or % utilization were found.

3.5. Discussion

Forage suitability evaluations in the northern climate of western Canada revealed valuable information regarding the use of chicory, birdsfoot trefoil, and alfalfa as deer forage, and while not planned, provided a useful assessment of alsike clover as deer pasture forage species. The evaluation of alternative forages, specifically those containing secondary compounds for improving productivity in grazing ruminants, has been recently reviewed by Ramirez-Restrepo and Barry (2005), and included an evaluation of chicory, birdsfoot trefoil, sulla (*Hedysarum coronarium*), alfalfa, white and red clover (*Trifoilum pratense* and *Trifolium repens*), and perennial ryegrass (*Lolium perenne*). Of the forages reviewed, it was concluded that chicory and the condensed tannin containing leguminous birdsfoot trefoil, as well as Sulla offered the most advantages (Ramirez-Restrepo and Barry, 2005).

3.5.1. Chicory

Our study indicates that Puna chicory established rapidly, similar to alfalfa, with good seedling competitive ability against weeds and volunteer clover. This supports Sanderson and Elwinger (2000) that showed that chicory developed three to four leaves with a root system capable of supporting this leaf mass by 40 to 50 days after planting in central Pennsylvania. Puna chicory suitability evaluations in the northern climes of Canada prior to this study were limited to Atlantic Canada (Kunelius and McRae; 1998), with persistence after 3 years considered acceptable. They also reported observations of naturalized chicory plants persisting in the region. While our study reports almost complete failure of stand persistence into the second year, studies in Pennsylvania (Labreveux et al., 2004) and New Zealand (Li et al., 1997[a]) have also found chicory stand losses after 1 year to be as high as 50% and 33% respectively, and up to 75% by year 4 with a 50% reduction in biomass (Li et al., 1997^b).

We did not measure physiologic variables that might reveal the reason for stand failure, although we did collect winter temperature data which may play an important role in chicory winter survival based on the following observations. January mean temperatures in our study area -17.2^0 C, which was 5.2^0 C colder than the Canadian study, and 11.6^0 C cooler than another Pennsylvanian study whose winterkill estimates were 30% after one year (Skinner and Gustine 2002). A more recent, unpublished study from southern Alberta, near the town of Brooks, which has a milder climate than Athabasca, reported good winter survival of chicory varieties originating from Europe (Dr. M. Bandara, Special Crops Research Scientist, Alberta Agriculture and Food-Crop development and Food, pers. communication, 2007). However, even under optimal management stand persistence of chicory is a maximum of 4 years (Barry 1998).

This studies findings on chicory protein (Foster et al., 2002; Holden et al., 2000), neutral detergent fiber (Turner et al., 1999; Foster et al., 2002) tannin concentrations (Schreurs et al., 2002), and growth patterns providing adequate quality forage for deer pasture through the summer (Jung et al., 1996; Volesky 1996) are consistent with the literature. Chicory biomass in northern Alberta (1904 kg·ha^{-1}) is greater than that of Atlantic Canada, reporting 985 kg·ha^{-1} and 687 kg·ha^{-1} in years one and three of the study, respectively (Kunelius and McRae 1998), our values remained considerably lower than in the northeastern United States, where yields ranged from 6028-7200 kg·ha^{-1}(Belesky et al., 1999; Sanderson et al., 2003;; Labreveux et al., 2004; Ball 2007). Moreover, chicory biomass levels documented here remained much lower than a New Zealand study reporting 9640 kg·ha^{-1}(Li et al., 1997^b). Soil quality, growing season length, and heavy fertilization and irrigation differences on our Luvisolic soils may be responsible for lower yields as compared to chicory grown in an intensively managed and irrigated system in southern Alberta on a dark brown chernozemic soil that produced 6400 kg·ha^{-1} of leaf matter, out yielding local corn silage crops with 5850 kg·ha^{-1} dry matter with chicory producing roots 7 cm in diameter and 22 cm in length (Dr. M. Bandara, Special Crops Research Scientist, Alberta Agriculture and Food-Crop development and Food, pers. communication, 2007). Comparatively, Wilson et al. (2004) reported root yields of 3600-5500 $kg\,ha^{-1}$ in Nebraska.

Preference for chicory, and the increased weight gain of deer grazing chicory seeded pasture, supports similar findings in deer (Kusmartono et al., 1996; Min et al., 1997; Schreurs et al., 2002), sheep (Komolong et al., 1992; Scales 1993;Scales et al., 1995; Fraser and Rowarth 1996; Fraser et al., 1988) and cattle (Barry 1998), indicating that where growing conditions are favorable, chicory is an excellent deer forage.

3.5.2. Birdsfoot Trefoil

Birdsfoot trefoil is considered valuable forage with more than 1 million ha seeded in the United States (Beuselinck and Grant 1995), but presently is not a widely used legume in Alberta because of problems in stand persistence (Alberta Agriculture and Food 2007 [b]). Nevertheless, birdsfoot trefoil is recommended as suitable pasture forage by the Alberta, Saskatchewan, and Manitoba departments of agriculture for climates and soil zones similar to our study region, and if managed carefully is thought to provide many years of stand life (Saskatchewan Agriculture and Food 2006; Alberta Agriculture and Food 2007 [a]; Manitoba Agriculture and Food 2007).

Our attempts to establish an acceptable stand of Leo birsdfoot trefoil failed in each of two seasons. Birdsfoot trefoil is considered difficult to establish as it has a small seed size, low seedling vigor, late maturity, and as a result, is a poor competitor (Hall 2007, Manitoba Agriculture and Food 2007, Alberta Agriculture and Food 2007 [a], Saskatchewan Agriculture and Food 2006). It was found that the inclusion of small grain companion crops at seeding reduced trefoil root development, seedling vigor, stand density, and biomass (Hall 2007). Our documented establishment of birdsfoot trefoil, with the lowest biomass, height, foliar cover, and greatest weed and volunteer clover biomass as compared to chicory and alfalfa, is consistent with expectations of limited establishment based on the literature. Weed and clover competition in our study was particularly high, with no means of weed control available, which therefore favored chicory and alfalfa forage establishment. Comparisons in weed and clover free soils would reduce this confounding factor and should be conducted.

Low season-long yields of birdsfoot trefoil compared with other legumes can be attributed to its slow regrowth and reliance on photo-assimilates rather than stored nonstructural carbohydrates (Smith 1962; McGraw and Martin 1986). High competition and poor establishment likely resulted in less vigorous plants contributing to the high observed winterkill, with other studies reporting winter kill after 1 year in milder climates to be 65% and 69% (Brummer and Moore 2000; McKenzie et al., 2004). Our biomass levels remained lower than first year yields from other regions of Canada, where trefoil biomass has ranged from 4900 to 5989 kg ha^{-1} (McKenzie et al., 2004; Cassida et al., 2000). While we were not able to evaluate 2nd year biomass levels of trefoil, other studies from western Canada have shown yields from 3250 kg ha^{-1} to 6299 kg ha^{-1} (Saskatchewan Agriculture and Food 2006; Alberta Agriculture and Food 2007 ^{a},; Manitoba Agriculture and Food 2007). Our lower biomass may be an indication of our agro-climatic region near Athabasca being poorly suited for birdsfoot trefoil, particularly when coupled with the loss in yield due to weed and volunteer clover competition. Similar to chicory, birdsfoot trefoil has no means of vegetative reproduction, leading to reductions in stand density over time, especially in highly stressed environments or grazing systems (Li et al., 1997; Ramirez-Restrepo and Barry, 2005).

While it is accepted that birdsfoot trefoil has several negative concerns associated with its use, it does have several benefits arising from its favorable forage quality. Birdsfoot trefoil crude protein and NDF concentrations were consistent with the literature (Jung et al., 1997; Waghorn et al., 2002; Ramirez-Resrepo and Barry, 2005), and high protein levels contributed positively to crude protein yields. Additionally, condensed tannin concentrations in birdsfoot trefoil were much greater than in any other forage examined. While tannin levels in trefoil can vary from as low as 2.3%-11%, with concentrations lowest in unstressed, monoculture stands (Barry and Forss 1983; Barry and Manley 1986; Lowther et al. 1987; Chiquette et al. 1988; Kelman and Tanner 1990; Roberts et al. 1993; Miller and Ehlke 1996; 1997; Waghorn et al., 2002; Gebrehiwot et al., 2002), variation in tannin levels throughout the growing season is common (Wen et al., 2003; Gebrehiwot et al., 2002). Tannin concentrations required to control bloat and increase amino acid absorption are 0.5% and 3-4%, respectively (Aerts et al., 1999; Ramirez-Restrepo and Barry 2005), below that of this studies average trefoil concentration of 5.37%: birdsfoot trefoil was the only forage examined here to exceed the CT % required to provide beneficial nutritional effects.

3.5.3. Alfalfa

Alfalfa was included in this trial as it is common used pasture forage for deer in Alberta with many varieties available for producers that are well adapted to all regions of Canada. Average biomass yields for the Athabasca area for Rangelander alfalfa in an established stand is 5664 $kg \cdot ha^{-1}$, which is greater than that of our first year yields of 3361 $kg \cdot ha^{-1}$. Nevertheless, alfalfa yields were as high as any other forage, and peaked relatively quickly following establishment. As expected, alfalfa quality (protein, tannin, and NDF levels) was high, consistent with the literature on the importance of including alfalfa to increase forage quality of pasture (Barnes and Scheafffer, 1995) Alfalfa is currently recommended as the first choice legume to seed for deer pasture in western Canada, with many studies and observations confirming that alfalfa is highly palatable to white-tailed deer when the plants are vegetative and/or actively growing (Grazing and Pasture Technology Program 1999). The greater yields of alfalfa compared to chicory and trefoil, coupled with high over-winter survival, suggests that this species should remain the primary forage of choice for deer production in northern Alberta.

Despite the favorable agronomic response of alfalfa, deer grazing alfalfa pasture gained the least weight, and when given a choice, deer preferred chicory over alfalfa. Alfalfa total digestible nutrients decrease noticeably in late summer, with mature plants much lower than plants 15-30cm in height, dropping from 62% to 45% TDN, while crude protein drops similarly from 20-30 % to 6-7%, respectively (Grazing and Pasture Technology Program 1999). A recent review of pasture forages for white-tailed deer in Saskatchewan recommended alfalfa forage quality could be improved later in the growing season by utilizing a rotational grazing system and maintaining alfalfa in a vegetative state by mechanically clipping or grazing alfalfa with cattle and *Bison bison* (Grazing and Pasture Technology Program 1999). Our evaluation of alfalfa for suitability as deer pasture reaffirms its reputation as good forage when we consider palatability, nutritional needs, forage yield, and stand persistence, although mixtures of trefoil or chicory with alfalfa may also be beneficial based on the attributes of those species as well.

3.5.4. Deer Feeding Preferences

Further evaluation of the palatability and preference of deer for alfalfa, chicory, and birdsfoot trefoil identified chicory as the forage that deer invested the most time grazing. Two main optimal foraging strategies exist including time minimization and energy maximization (Renecker and Hudson 1993) with seasonal changes between the two strategies (Belovsky 1984). White-tailed deer select an energy maximizing diet in winter (Schmitz 1990) and mule deer maximize energy intake when forage conditions are poor and minimize foraging time when conditions are good (Kie 1996). In addition, wild deer diet analysis suggests that most deer select plants or plant parts that are highest in protein and digestibility (Putman 1988; Racz et al., 1999), generally preferring the more succulent species with larger and thinner leaves (Dayton 1931). Based on these studies, it is not surprising that chicory was most preferred as it has the largest and thinnest leaves, was lowest in NDF, and had similar crude protein concentrations compared to birdsfoot trefoil and alfalfa during the preference study. Deer could therefore minimize time and furthermore maximize energy intake by grazing chicory. Forage availability observations not captured in the numerical data identified chicory availability to be severely declining by the third and final period of the preference trial, probably causing the marked decline by over 6% in time spent grazing by deer within chicory in last period of the trial.

Differences in percent utilization and RPI, although not significant, identified birdsfoot trefoil and chicory to be more preferred forages. Birdsfoot trefoil availability was lowest of all forages, and although this species had similar plant densities to chicory and alfalfa, they were small plants, the combination of which would require high search times by deer to consume equal amounts of trefoil as compared to the others. Consequently, birdsfoot trefoil experienced high utilization and represents a behavior by deer to consume it to a higher degree when encountered. Deer grazing mixed forage stands have been found to prefer birdsfoot trefoil over the other available forages (Adu et al., 1998) and roe deer have the ability to accurately select for tannins (Clauss et al., 2003), known to be greater in trefoil in the current study. Despite this, no quantitative relationship was found between tannin concentration in forage type and any of the three white-tailed deer preference indices, including utilization (kg ha^{-1} and %) and the RPI.

Weight gains were greatest in deer grazing chicory and birdsfoot trefoil. The improved weight gains of deer grazing chicory may be attributed to the reduced NDF concentrations, leading to higher forage digestibility, digesta flow rates, and dry matter intake (Kusmartomo et al., 1997) with higher voluntary consumption related to rates of digestion rather than sensory perceptions of the herbage (Church 1979). Interestingly, deer grazing birdsfoot trefoil gained similar to deer grazing chicory (in this study), despite 10.5% greater NDF in this study and a 9% lower dry matter digestibility (as measured by Waghorn et al., (2002). Waghorn et al., (2002) found that deer grazing birdsfoot trefoil gained more than deer grazing alfalfa that was of similar quality (Waghorn et al., 2002). The key to this increased performance may lie in the condensed tannin concentration of birdsfoot trefoil, which in this study was 5% greater than alfalfa and chicory.

Condensed tannins in birdsfoot trefoil have been found to reduce rumen protein degradability leading to greater essential amino acid absorption from the small intestine (Waghorn et al., 1987) when tannin concentrations are above 3-4% (Ramirez-Restrepo and Barry, 2005). Compared to alfalfa, birdsfoot trefoil at similar growth stages had similar crude protein and NDF concentrations, and greater digestible energy estimates (Hall 2007, Cassida et al., 2000). Marten et al. (1987) found greater weight gain in heifers grazing birdsfoot trefoil over alfalfa monocultures. Barry et al. (1997) linked tannins in birdsfoot trefoil to increased weight gains in red and hybrid deer as compared to animals grazing chicory. Relative to other forages, birdsfoot trefoil tannins have been linked to improvements in cattle, deer, and sheep performance, with mechanisms for improvements being attributed to essential amino acid absorption (Ramirez-Restrepo and Barry 2005).

Lack of preference for alfalfa may be attributed to the presence of sapponins that are known to reduce rumen motility (Klita et al. 1996) and coumestan produced by foliar disease during late summer/autumn, which depresses reproductive performance (Smith et al., 1979, 1980). Unlike alfalfa, trefoil and chicory do not contain appreciable amounts of sapponins.

Deer weight gain was highest in chicory and birdsfoot trefoil suggesting these forages are both better than the alfalfa forage. Plant diversity as evidenced by weed bimass was also greater in these paddocks and additionally clover biomass was greater in these paddocks. As no link between forage type consumed and tannin concentration was found it seems reasonable to conclude that these factors most likely contributed to some of the increase in weight gain as deer, when given feed choice can select the most nutritionally available plant components available (Boodoo et al. 1988; Aboud et al. 1990) and furthermore it was found that mule deer select forages containing both the highest digestible dry matter and the lowest nontannin phenolics (McArthur et al., 1993). Provenza et al., (2003) suggests that diversity is critical for ingesting both nutrients and toxins and when given a choice of feeds containing different toxins, animals eat more feed than animals given only 1 feed (Dearing and Cork, 1999; Burritt and Provenza, 2000, Chapter 2 this study). This diet diversity and allowance for selection is likely one of the reasons wild deer have the ability to detoxify toxins better than penned deer (Harborne 1977).

Volunteer alsike clover represented a significant confounding factor in the investigation here of deer performance and feeding preference, as well as forage establishment and agronomic characteristics. Clover quality and productivity in this study reveal that it is particularly well adapted to this region with up to 3188 $kg \cdot ha^{-1}$ biomass and an average of 1683 $kg \cdot ha^{-1}$. This level approaches or exceeds the average yields of established stands in the region of 2830 $kg \cdot ha^{-1}$ (Alberta Agriculture and Food, 2007c). Although the performance of deer grazing exclusively alsike clover was not measured, deer did have the opportunity to consume it in all seeded forage types. For example, within the birdsfoot trefoil performance trial pens, the forage type that exhibited the greatest weight gains, alsike clover forage availability was more than 4 times that of trefoil. This fact combined with the high observed variance in forage utilization raises the question as to the degree to which deer weight gain can be attributed to the birdsfoot trefoil rather than clover. Seasonal patterns of alsike clover growth demonstrated consistent quality and biomass providing deer with excellent quality nutrition throughout the entire growing season. Alsike clover is a short lived perennial, has a high regrowth capacity, reproduces vegetatively and commonly reseeds itself, all of which contribute to good stand persistence. Based on the unintended information obtained for clover in this study, we also recommend alsike clover as a suitable deer pasture based on this limited information, but stress the need for more research focused on deer performance grazing this forage and other clovers adapted to the region.

3.6. Conclusions

Forage suitability evaluations for deer pasture requires 4 main considerations: Palatability, seasonal nutritional needs of deer, forage yield, and stand persistence. Based on this study, the following conclusions can be drawn:

1. Chicory is high in quality, low in tannin concentration, preferred by deer, improves deer weight gain in a diverse stand, and establishes well, but may not withstand the cold winters of northern Alberta. Therefore, while suitable as annual forage, we do not recommend chicory as perennial pasture forage in this region unless winter hardiness can be enhanced.

2. Birdsfoot trefoil forage quality, together with associated deer preference and weight gains in a diverse stand, indicates trefoil is excellent pasture forage for deer. However, we do not recommend it for use in the Athabasca region due to slow establishment and poor persistence with high winter. Furthermore we do not recommend that birdsfoot trefoil be seeded into weedy fields, stressing that crop management planning is paramount to ensure successful establishment.

3. Our evaluation of alfalfa for suitability for deer pasture reaffirms its reputation as good forage providing a high quality, persistent, and palatable forage for deer. We recommend producers continue to use alfalfa as deer pasture forage but suggest that other forages may improve weight gain in some regions. Mixtures of alfalfa with other forages may also prove beneficial, although was not critically evaluated.

4. Although not deliberately tested, our results support the notion of alsike clover as favorable deer forage for this region, possibly similar to chicory and birdsfoot trefoil, and potentially better than alfalfa at recommended seeding rates. Furthermore its quality and productivity is maintained throughout the season. More directed study is needed to evaluate the suitability of clover species for deer pasture in Alberta.

5. Tannin containing forages show potential for improving the productivity of deer production. In this study deer did not consume forages in relation to their tannin concentration, but did prefer forages with high tannin concentration. Further study is needed in this area for which we suggest the use of cafeteria trials (i.e. controlled availability under dry lot conditions) of daily harvested forages in order to eliminate confounding factors (i.e. neighboring vegetation other than that seeded).

6. Deer are highly variable and sensitive animals and we recommend that trial designs maximize statistical power. In addition, effectively evaluating forage suitability requires distinct monocultures to make clear comparisons with low repetition and every precaution taken to minimize variability in plant productivity between and within replications.

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3.8 Tables

Table 3.1 Environment Canada long term climate norms for Athabasca, Alberta. Climate station (2*) ID # 3060321 (Lat. 54° 49' N, Long 113° 31' W, Elevation 626m asl).

Temperature:	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Daily Average (°C)	-14.9	-10.7	-4.4	**4.2**	**10.6**	**14.2**	**16.2**	**15.2**	**9.8**	**4.1**	-6.2	-12.9	2.1
Standard Deviation	4.8	5	3.3	2.2	1.5	0.9	1	1.8	1.8	1.7	3.8	4.7	1.3
Daily Max (°C)	-10	-5.2	1.2	10.5	17.1	20.3	22.2	21.2	15.5	9.3	-2.1	-8.3	7.6
Daily Minimum (°C)	-19.9	-16.2	-10	-2.1	4	8.1	10.1	9	4	-1.2	-10.2	-17.4	-3.5
Precipitation:													
Rainfall (mm)	0.6	0.7	1.4	**15.1**	**45.3**	**91.7**	**104.5**	**62.6**	**41.4**	**15.3**	2	1.1	382
Snowfall (cm)	24.3	17.9	16.3	10.4	2	0	0	0	1.4	6.1	19.1	24.4	122
Precipitation (mm)	24.9	18.6	17.7	25.5	47.3	91.7	104.5	62.6	42.8	21.5	21.1	25.5	504
Average Snow Depth (cm)	26	31	23	3	0	0	0	0	0	1	7	17	
Snow Depth at Month-end (cm)	30	31	10	1	0	0	0	0	0	3	11	20	
Minimum Temperature: > 0 °C	0.31	0.5	0.73	8.9	25.6	29.8	31	30.7	24.5	11.3	0.9	0.37	165
Degree Days: Above 5 °C	0.3	0.6	1.3	47.6	177.8	278.3	346.1	314.6	153.6	47.9	1.5	0.3	1370

Table 3.2 Environment Canada 2003-2005 climate data for Athabasca, Alberta. Climate Station (2*) ID # 3060321, (Lat. 54° 49' N; Long. 113° 31' W; Elevation 626 m asl)

Month	Mean Max Temp °C	Mean Min Temp °C	Mean Temp °C	Rainfall (mm)	Snowfall (cm)	Total Precipitation Equivalent	Killing Frost, °C
Apr03	9.2	-1.9	3.7	**8.4**	15	23.4	
May03	15.2	3.3	9.3	**28.2**	17.5	45.7	
Jun03	20.1	9.5	14.8	**149.3**	0	149.3	
Jul03	23.1	11.2	17.3	**78.1**	0	78.1	
Aug03	22.7	9.9	16.3	**35.8**	0	35.8	
Sep03	16.2	4.2	10.2	**14.8**	0	14.8	Sept 24, 4 °C
Oct03	11.4	-0.1	5.6	**15.9**	3	18.9	
Nov03	-3	-14	-8.5	0	20.5	20.5	
Dec03	-5.5	-17	-11.2	0	14	14	
Jan04	-12.9	-21.5	-17.2	0	43	43	
Feb04	1.9	-15.2	-8.5	0	7	7	
Mar04	2.2	-7	-2.4	0	17	17	
Apr-04	11.2	-2.4	4.4	**10**	22	32	
May04	13.2	1.7	7.5	**69.7**	0	69.7	
Jun-04	20.9	7.3	14.1	**11.7**	0	11.7	
Jul-04	22.9	12.2	17.6	**165.9**	0	165.9	
Aug04	19.9	8.8	14.4	**60.9**	0	60.9	
Sep04	13.4	3.2	8.3	**78**	0	78	
Oct04	6.1	-3.6	1.3	**8.5**	26	34.5	Oct. 1, -6 °C
Nov04	2.5	-5	-1.3	12.5	2	14.5	
Dec04	-5.5	-16.8	-11.2	0	37	37	
Jan05	-8.2	-17.4	-12.8	0	10	10	
Feb05	-2	-12.6	-7.3	0	2	2	
Mar05	3.3	-6.7	-1.7	6	6	12	
Apr05	12.4	0.2	6.4	6.8	5	11.8	
May05	17.3	3.1	10.2	60	0	60	

Table 3.3. Summary of plot areas and intended use within various blocks of the forage evaluation, deer performance, and deer selection trials.

	Block						
	1	2	3	4	5	6	7
Forage Type	----------ha--------		---------------------m^2---------------------------				
Alfalfa	0.92	0.82	169	169	169	169	169
Birdsfoot Trefoil	0.87	0.53	169	169	169	169	169
Chicory	0.68	0.70	169	169	169	169	169
Intended use							
Forage Trial	x	x	x	x	x	x	x
Deer Performance	x	x					
Deer Selection			x	x	x	x	x

Table 3.4. Deer weight gain and selection trial pen sizes, forage availability, stocking rates, and grazing pressure.

Pen	Forage	Size	Grazing Period	AU	Seeded Forage Availability	Forage and Clover Availability	Stocking Rate	Forage Grazing Pressure	Clover and Forage Grazing Pressure
		ha			kg·ha^{-1}	kg·ha^{-1}	AUM·ha^{-1}	z	z
1	Chicory	0.68	30 July-19 Sep	0.80	743	1840	1.92	1.9	0.8
2	Birdsfoot trefoil	0.87	30 July-19 Sep	0.87	132	1274	1.64	11.9	1.2
3	Alfalfa	0.92	30 July-19 Sep	1.37	843	1872	1.10	2.9	1.3
4	Alfalfa	0.82	30 July-19 Sep	1.20	762	1540	1.12	2.9	1.4
5	Chicory	0.70	30 July-19 Sep	0.85	540	1840	1.34	2.9	0.8
6	Birdsfoot trefoil	0.53	30 July-19 Sep	0.72	62	846	1.21	21.0	1.5
7	Matrix	0.254	31 Jul-17 Aug	0.66	301	456	1.45	3.9	2.6

[z] Theoretical grazing pressure (i.e. ratio of forage demand to forage available) assuming deer dry matter intake is 4 % of known body weights calculated as % of available forage removed·day^{-1}.

Table 3.5. Summary of ANOVA results for measures taken of alfalfa, birdsfoot trefoil, and chicory forage establishment, 69 days post seeding in 2003 and 2004, including mean forage height, cover, biomass, protein content, neutral detergent solubles, condensed tannin, and mean weed and volunteer clover biomass.

Response	n	Num DF	Den DF	P>F
Height (cm)				
Forage	7	2	31	**<0.0001**
Year	2	1	31	**<0.0001**
Year*Forage		2	31	**<0.0001**
Cover (%)				
Forage	7	2	32	**<0.0001**
Year	2	1	32	**0.02**
Year*Forage		2	32	**0.01**
Forage Density (plants m^{-2})				
Forage	7	2	32	0.94
Year	2	1	32	**<0.0001**
Year*Forage		2	32	0.31
Seeded Forage Biomass (kg ha^{-1})				
Forage	7	2	31	**0.0003**
Year	2	1	31	**0.04**
Year*Forage		2	31	**0.01**
Protein (%)				
Forage	7	2	32	**<0.001**
Year	2	1	32	0.91
Year*Forage		2	32	0.27
Neutral Detergent Solubles (%) [Z]				
Forage 2004	7	2	18	**0.03**
Condensed Tannin (%)				
Forage	7	2	24	**<0.0001**
Year	2	1	24	**0.0009**
Year*Forage		2	24	0.08
Volunteer Clover Biomass				[y]
Weed Biomass (kg ha^{-1}) [X]				
Forage 2004	7	2	30	**0.002**

[Z] NDS was not determined for samples collected in 2003.

[Y] See Table 3.8 for clover yield comparisons. [X] Weed biomass was collected only in 2004.

Table 3.6. Alfalfa, birdsfoot trefoil and chicory establishment measures as assessed 69 days after seeding in 2003 and 2004.

	Year						Grand Mean		
	2003			2004					
Response	**Alfalfa**	**Birdsfoot**	**Chicory**	**Alfalfa**	**Birdsfoot**	**Chicory**	**Alfalfa**	**Birdsfoot**	**Chicory**
Forage Height (cm)	25 (1.5) a[z]	18 (1.4) b	21(1.4) ab	46 (1.4) a	25 (1.3) b	28 (1.3) b	35(1) A[Y]	21(0.9) C	24(0.9) B
Forage Cover (%)	42(5.6) b	37(5.1) b	77.6 (5.1)a	73 (4.7) a	39 (4.7)b	75(4.7) a	57 (3.7) B	38 (3.5) C	76.(3.5) A
Forage Density (shoots m^2)	90 (29)	136 (27)	110 (27)	257(24)	224 (24)	256(24)	174 (19)	180 (18)	184 (18)
Forage Biomass (kg ha^{-1})	1363 (215) b	1227 (215) b	1924 (197) a	1701 (183) a	498 (183) b	1350 (183) a	1532 (152) A	862(152) B	1638 (146) A
Clover Biomass (kg ha^{-1})	-	-	-	560 (121) a	620 (121) a	630 (121) a	-	-	-
Protein (%)	21.3 (1.6)	14.6 (1.5)	14.4 (1.5)	19.6 (1.4)	14.6 (1.4)	16.6 (1.4)	20.5 (1.3) A	14.6 (1.2) B	15.5 (1.2) B
Forage NDS (%)	n/a	n/a	n/a	55.1(1.5) ab	53.1(1.5) b	59.2 (1.5) a	n/a	n/a	n/a
Tannin (%)	0.53 (0.42)	6.69 (0.42)	2.0 (0.42)	0.34 (0.26)	5.17 (0.26)	0.36 (0.26)	0.44 (0.25) C	5.94 (0.24) A	1.17 (0.24) B
Weed Biomass (kg ha^{-1})	-	-	-	1070 (246) b	2141 (246) a	656 (246) b	-	-	-

[Y] Within a row, grand means with different uppercase letters differ significantly ($p<0.05$)

[z] Within a row and year, means with different lowercase letters are significantly different ($p<0.05$)

Table 3.7. Over-winter survival data from May 2004 of forages seeded in 2003.

		Forage			
Response	**n**	**Alfalfa**	**Birdsfoot Trefoil**	**Chicory**	**P>F**
Live Foliar Cover (%)	7	25.2 (5.4)a [z]	0.3 (5.0) b	1.8 (5.0) b	**0.006**
DeadFoliar Cover (%)	7	4.8 (5.6) c	39.9 (5.2) b	58.2 (5.2) a	**<0.0001**
Density Live (plants m^{-2})	7	37.7 (8.0) a	1.1 (7.44) b	6.6 (7.44) b	**0.009**
Density Dead (plants m^{-2})	7	14.8 (11.3) b	62.0 (10.5) a	63.9 (10.5) a	**0.009**
Total Live & Dead Density (plants m^{-2})	7	52.4 (12.8)	63.1 (11.8)	70.6 (11.8)	0.60

[z] Within a row, means with different lowercase letters are significantly different ($p<0.05$).

Table 3.8. Mean standing biomass (SE) of alfalfa, birdsfoot trefoil, chicory, volunteer clover and weeds within each of the 3 seeded forage types, as sampled in July, August and September of 2004.

	Forage Type		
Month	**Alfalfa**	**Birdsfoot**	**Chicory**
	------------------------- kg ha^{-1}	--------------------------	
Seeded Forage Biomass			
Jul-25	B^{z} 1701(275) a^{y}	B 498 (275) c	A 1351 (275) b
Aug-17	A 3339(460) a	AB 1009 (460) b	A 1562 (460) b
Sep-19	A 3361 (447) a	A 1601 (447) b	A 1904 (447) b
All Times	2800 (330) a	1026 (330) b	1606 (330) b
Effect		**n**	**P >F**
Forage		7	**<0.0001**
Month		3	**<0.0001**
F*M			**0.05**
Volunteer Clover Biomass Within Forage Type			
Jul-25	560 (121)	620 (121)	630 (121)
Aug-17	682 (259)	889 (259)	1183 (259)
Sep-19	1127 (294)	2226 (294)	1696 (294)
All Times	790 (155) b	1245 (155) a	1170 (155) a
Effect		**n**	**P >F**
Forage		7	**0.07**
Month		3	**<0.0001**
F*M			0.11
Seeded Forage and Clover Biomass			
Jul-25	B 2262 (392) a	B 1118 (392) b	B 1981 (392) a
Aug-17	A 4088 (437) a	B 1806 (437) b	B 2642 (437) ab
Sep-19	A 4488 (392) a	A 3827 (392) ab	A 3600 (392) b
All Times	3613 (320) a	2251 (320) b	2741 (320) b
Effect		**n**	**P >F**
Forage		7	**<0.0001**
Month		3	**<0.0001**
F*M			**0.06**

Table 3.8. Continued.

Month	Forage Type		
	Alfalfa	Birdsfoot	Chicory
	kg ha^{-1}		
Seeded Forage Biomass			
Jul-25	B[z] 1701(275) a[y]	B 498 (275) c	A 1351 (275) b
Aug-17	A 3339(460) a	AB 1009 (460) b	A 1562 (460) b
Sep-19	A 3361 (447) a	A 1601 (447) b	A 1904 (447) b
All Times	2800 (330) a	1026 (330) b	1606 (330) b

Effect	n	P >F
Forage	7	**<0.0001**
Month	3	**<0.0001**
F*M		**0.05**

[z] Within a column, means with different uppercase letters are significantly different (p<0.05).

[y] Within a row, means with different lowercase letters are significantly different (p<0.05).

Table 3.9. Mean (SE) crude protein, neutral detergent fiber, and condensed tannin content of the seeded forages as sampled in July, August and September of 2004.

	Forage Type		
Month	**Alfalfa**	**Birdsfoot**	**Chicory**
		--(%)--	
Seeded Forage Crude Protein Content			
Jul-25	19.6 (1.6)	14.6 (1.6)	16.6 (1.6)
Aug-17	16.1 (1.3)	11.9 (1.3)	14.2(1.3)
Sep-19	12.9 (0.7)	11.7 (0.7)	11.4 (0.7)
All Times	16.2 (1.0) a[Y]	12.7 (1.0) b	14.1 (1.0) ab
Effect		**n**	**P >F**
Forage		7	**0.04**
Month		3	**<0.0001**
F*M			0.27
Seeded Forage Neutral Detergent Fiber Content			
Jul-25	B[Z] 44.9 (1.3) ab	A 46.9 (1.3) a	A 40.9 (1.3) b
Aug-17	B 45.3 (1.5) a	A 43.7 (1.5) a	C 30.5 (1.5) b
Sep-19	A 52.0 (1.3) a	A 49.3 (1.3) a	B 36.6 (1.3) b
All Times	47.4 (0.8) a	46.6 (0.8) a	36.0 (0.8) b
Effect		**n**	**P >F**
Forage		7	**<0.0001**
Month		3	**<0.0001**
F*M			**<0.001**
Seeded Forage Condensed Tannin Content			
Jul-25	0.35 (0.30)	5.17 (0.30)	0.36 (0.30)
Aug-17	0.39 (0.37)	6.02 (0.37)	0.44 (0.37)
Sep-19	0.49 (0.54)	4.71 (0.54)	0.66 (0.54)
All Times	0.41 (0.29) b	5.37 (0.29) a	0.49 (0.29) b
Effect		**n**	**P >F**
Forage		7	**<0.0001**
Month		3	**0.02**
F*M			0.11

[Z] Within a column, means with different uppercase letters are significantly different ($p<0.05$).

[Y] Within a row, means with different lower case letters are significantly different ($p<0.05$).

Table 3.10. Summary of volunteer clover crude protein, NDF and condensed tannin content, within each seeded forage type during 2004.

Month	Seeded Forage Type			
	Alfalfa	Birdsfoot Trefoil	Chicory	n[Y]
		Clover Protein (%)		
July	15.8	17.5	21.9	1
August	21.3	15.7	13.1	1
September	11.9	15.0	12.8	1
All	**16.3**	**16.1**	**16.0**	
		Clover NDF (%)[Z]		
July	37.4	39.6	34.9	1
August	38.3	33.4	37.6	1
September	49.5	44.8	41.3	1
All	**41.3**	**38.9**	**38.0**	
		Clover Tannin (%)		
July	0.16	0.29	0.24	1
August	0.72	0.97	0.72	1
September	0.70	2.08	1.82	1
All	**0.53**	**1.11**	**0.93**	

[Z] Neutral Detergent Fiber

[y] 1 sample was taken within each time period and used to calculate nutrient yield of clover.

Table 3.11. Mean (SE) crude protein yield (CPY) of each seeded forage type, volunteer clover, and total forage type and clover, in July, August and September, 2004.

Component	Forage Type		
Month	Alfalfa	Birdsfoot	Chicory
	------------------------- kg ha^{-1}	-------------------------	
Seeded Forage Crude Protein Yield			
Jul-25	^{z} 309 (50) ^{y}	132 (50)	204 (50)
Aug-17	411 (84)	193 (84)	207 (84)
Sep-19	406 (52)	198 (52)	159 (53)
All Times	375 (55) a	174 (55) b	190 (55) b
Effect		**N**	**P >F**
Forage		7	**0.02**
Month		3	0.14
F*M			0.45
Volunteer Clover Crude Protein Yield			
Jul-25	A 97 (19) a^Y	B 116 (19) a	A 142 (19) a
Aug-17	A 170 (39) a	B 146 (39) a	A 143 (39) a
Sep-19	A 164 (37) ab	A 311 (35) a	A 145 (40) b
All Times	**144 (22)**	**191 (22)**	**143 (22)**
Effect		**N**	**P >F**
Forage		7	0.12
Month		3	**0.001**
F*M			**0.01**
Total Seeded Forage and Volunteer Clover Crude Protein Yields			
Jul-25	B^z 405 (61) a	B 247 (61) a	A 346 (61) a
Aug-17	A 620 (98) a	AB 397 (98) a	A 331 (98) a
Sep-19	AB 563 (53) a	A 509 (52) a	A 319 (56) a
All Times	**529 (60) a**	**384 (60) b**	**332 (60) b**
Effect		**N**	**P >F**
Forage		7	**0.07**
Month		3	**0.01**
F*M			**0.02**

[z] Within a column, means with different uppercase letters are significantly different ($p<0.05$).

[y] Within a row, means with different lower case letters are significantly different ($p<0.05$).

Table 3.12. Mean (SE) neutral detergent soluble yield of alfalfa, birdsfoot trefoil, chicory, volunteer clover and total forage in July, August and September, 2004.

Component	**Forage Type**		
Month	**Alfalfa**	**Birdsfoot**	**Chicory**
	----------------------------	kg ha^{-1}(SE)	--------------------------
Seeded Forage Neutral Detergent Soluble Yield			
Jul-25	893 (160)	450 (160)	746 (160)
Aug-17	1508 (211)	614 (211)	841 (211)
Sep-19	1506 (209)	854 (206)	1116 (215)
All Time	1303 (162) a^{z}	640 (162) b	901 (162) b
Effect		**N**	**P >F**
Forage		7	**0.007**
Month		3	**0.003**
F*M			0.25
Volunteer Clover Neutral Detergent Soluble Yield			
Jul-25	370 (62)	385 (62)	430 (62)
Aug-17	508 (148)	581 (148)	639 (148)
Sep-19	673 (145)	1146 (136)	673 (158)
All Time	517 (82)	704 (80)	581 (84)
Effect		**N**	**P >F**
Forage		7	0.16
Month		3	**<0.0001**
F*M			0.13
Total Seeded Forage and Vol. Clover Neutral Detergent Soluble Yield			
Jul-25	1264 (184)	836(184)	1176(184)
Aug-17	2075 (279)	1442 (278)	1301 (282)
Sep-19	2147 (221)	2000 (217)	1850 (229)
All Time	1828 (192)	1426 (192)	1264 (192)
Effect		**N**	**P >F**
Forage		7	0.26
Month		3	**<0.0001**
F*M			0.12

[z] Within a column, means with different uppercase letters are significantly different ($p<0.05$).

[y] Within a row, means with different lowercase letters are significantly different ($p<0.05$)

Table 3.13. Observed pasture forage selection during grazing (% of foraging time) of white-tailed deer offered a choice of 3 forages in August 2004.

	Seeded Forage Type			
Trial Period	**Alfalfa**	**Birfoot Trefoil**	**Chicory**	**SE**
Early	27.6	31.4	41.3	3.7
Mid	28.2	27.0	39.9	3.7
Late	31.5	28.0	33.8	3.7
WholeTrial	29.1b[Z]	28.8 b	38.4 a	1.9
Effect			**N**	**P>F**
Forage			3	**0.02**
Trial Sampling			3	0.76
Forage*Period				0.60

[z] Means in rows with different letters differ, $p<0.05$.

Table 3.14. Comparison of mean (SE) forage availability, utilization and relative preference index (RPI) by white-tailed deer offered 3 seeded forages and 2 volunteer forage classes.

Forage Type	**Forage Availability**	**Utilization**	**Utilization**	**RPI**	**n**
	----- kg ha^{-1} ----	--- kg ha^{-1} --	------- % ------	-- index --	
Alfalfa	1226 (165) ab[Z]	352 (127)	24.6 (10.5) ab	0.57 (0.61)	5
Birdsfoot	485 (184) b	243 (142)	52.0 (11.7) a	2.11 (0.69)	5
Chicory	623 (184) ab	288 (142)	39.7 (11.7) ab	1.40 (0.69)	5
Vol. Clover	845 (184) ab	38 (127)	3.3 (10.5) b	0.72 (0.61)	5
Vol. Weeds	1305 (165) a	222 (127)	17.9 (10.5) ab	0.57 (0.61)	5
P>F	**0.02**	0.52	**0.06**	0.42	5

[Z] Within a column, means with different letters differ, $p<0.05$.

Table 3.15. Weight gain of white-tailed deer grazing pens seeded to 1 of three separate forages.

Seeded Forage	N	Weight Gain	SE
		-g kgmbw^{-1} day^{-1}-	
Alfalfa	2	3.53 b^z	0.74
Birdsfoot	2	9.12 a	0.74
Chicory	2	7.50 a	0.74

^{z} Column means with different letters are significantly different, $p<0.10$.

Table 3.16. Forage availability and utilization by white-tailed deer grazing areas seeded to one of 3 forages in the performance trial.

	Vegetation Component			
Seeded Forage	**Weeds**	**Clover**	**Seeded Forage**	**SE**
		Forage Production		
		(kg ha^{-1})		
Alfalfa	269	892	1806	314
Birdsfoot	592	3188	753	314
Chicory	884	768	1390	314
Total[y]	581 b[z]	1615 a	1316 a	181
Effect		**n**	**P >F**	
Forage		3	0.15	
Vegetation Type		3	0.02	
Forage*Veg type			0.26	
		Forage Utilization		
		(%)		
Alfalfa	-1.35	23.4	7.7	31.3
Birdsfoot	52.2	71.1	-11.8	49.5
Chicory	-41.4	65.2	4.0	31.3
Total[y]	-1.35	23.4	7.7	31.3
Effect		**n**	**P >F**	
Forage		3	0.56	
Vegetation Type		3	0.16	
Forage*Veg Type			0.53	
		Forage Utilization		
		(kg ha^{-1})		
Alfalfa	11.5	856	46.4	393
Birdsfoot	1656	529	-294	621
Chicory	-307	889	78	393
Totally	11.5	856	46.4	393
Effect		**n**	**P >F**	
Forage		3	0.54	
Vegetation Type		3	0.17	
Forage*Veg Type			0.13	

[z] Within a row, means with different lower case letters are significantly different ($p<0.05$).

[y] Total vegetation type within forage.

3.9. Figures

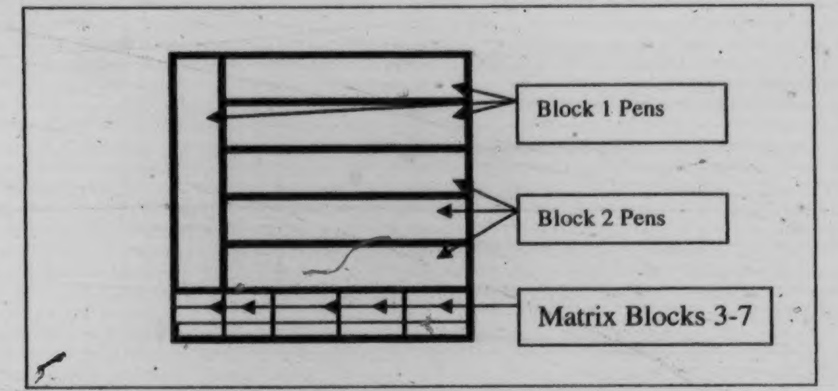
Block 1 Pens
Block 2 Pens
Matrix Blocks 3-7

Figure 3.1 Forage trial blocks, pens, and plot layout

4.0. Synthesis

White-tailed deer possess unique morphophysiological adaptations which have determined their dietary niche and subsequent concentrate selecting ruminant classification (Hoffmann 1989). Although very adaptable, several key limiting factors affect the nutrition and performance of WTD which entail critical considerations to maximize efficiency, sustainability, and success of their management and production.

White-tailed deer do not make efficient use of grass pasture (Hans-Joachim 1997; Hudson et al., 2000) and as such, the successful establishment and provision of palatable forages, that meet known seasonal and physiological nutritional requirements (Feist 1998, as appears in Klein 1999 (Table 5.6) combined with an understanding of subsequent foraging behavior is necessary to enhance their productivity, and is typically the least expensive means of feeding ruminants. Northern climates create even greater seasonal challenges when suitable forage availability and quality is limiting, necessitating supplementation and provision of alternative diets. Little is known about the feeding science of WTD, relative to domestic livestock, and much remains to be learned. Research on the effects of available supplements that show potential for improving management systems is critical to the development of diets that enhance WTD health and productivity during these times.

In general this project was conducted to yield valuable information on the digestive adaptations of North American browsing ruminants and specifically the WTD digestive adaptations to condensed tannins. Secondly through the evaluation of both annual and perennial forages we wanted to identify alternative forages capable of meeting WTD nutritional needs.

Specifically, the first study involved the determination of the feeding value of condensed tannins by testing the effects of two sources of condensed tannins on white-tailed deer performance. The second objective was to determine if WTD exhibit a compensatory growth pattern in the spring of the year. The specific objectives of the second and third studies were to evaluate the suitability of Alfalfa, Chicory and Birdsfoot trefoil perennial forages and Berseem Clover, Canola, Peas, and Turnips annual forages for their suitability for deer pasture.

These results of this study can be synthesized into 3 areas for discussion; 1) working with seasonality of deer capitalizing on compensatory gain, 2) evaluating alternative forages and 3) exploring the use of supplemental tannins to improve the nutritional characteristics of conventional forages.

4.1 Seasonality

Comprehension of the combined spring seasonal physiological factors that influence feeding efficiency (Worden and Pekins 1995)(i.e. compensatory growth) was one of the primary objectives of this study as it has potential for reducing expensive winter feeding costs and maximizing efficient weight gains when pasture forage becomes available in spring. Although no spring body weight proved to gain more efficiently than another, this conclusion may be confounded by body condition differences between individuals and needs further investigation. WTD exhibit strongly seasonal growth and appetite that was markedly higher during spring and summer. Improvement of body condition during these summer months on forages that are likely less expensive than provision of winter feed alternatives, may be the most efficient management system. Pasture grazing system and management should be a priority to capitalize growth during this period as appetite and growth slows during the winter months. Ensuring optimal body weight is achieved entering winter also has the added benefit of reducing winter feed energy requirements and feed costs as thermal insulation associated with superior fat reserves would reduce their necessity (Mautz 1978). Adopting this management system may be the most efficient system for production of WTD but may not be optimal for farm income if trophy deer are the goal of production as nutritional requirements of this type of herd are greater.

4.2. Alternative forages

The second portion of this study evaluated alternative annual and perennial pasture forages for WTD grazing during the summer to provide farmers and wildlife enthusiasts with better information and recommendations on there use in order to reduce feeding costs. Evaluation of any forage involves understanding of there agronomic traits associated with quality, biomass production, nutrient yield, and persistence as they all affect forage suitability. Perhaps more importantly, it is necessary to understand the palatability of these forages and their plant parts and how changes in plant phenological stage affect WTD foraging behavior, preferences, and subsequent performance. Deer were identified as being highly selective in their foraging choices between and within forages, which changed with forage availability and season. This supports other studies (Putman 1988; Racz et al., 1999) where WTD to have the ability to identify and select the highest quality forage available selecting a diet that maximizes protein intake and forage digestibility. This is critical to be able to predict utilization of the forage and how crop management may be altered to ensure grazing systems are successful.

No economic evaluation was conducted as part of this study however enough information is provided to enable farmers to assess the sensitivity of economics to their unique management systems and goals. Stand persistence is a critical requirement of perennial pasture forage in reducing grazing costs. Perennial forages are usually a more cost effective and less intensive pasture forage choice permitting stands establish well and persist. Compared to annuals they are often more difficult to establish and are less productive in the first year. Alfalfa and alsike clover have been reinforced as two good perennial forages. Although we cannot conclude that birdsfoot trefoil grazing improves the performance of deer we are certain that chicory is good deer forage that may be feasible in milder regions of Alberta.

Utilizing a system that employs a combination of both annual and perennial forages can improve forage quality and extend the grazing season where snow depth is not limiting. Turnips, Peas, and Berseem clover are all excellent choices while research on crop management and agronomics of other annual species is needed to improve the viability of their use. Farmers are encouraged to adopt their use and utilize the many other sources of information available in the cattle livestock industry that with some general understanding of WTD requirements and crop production could be applied to WTD production.

The highly selective foraging behavior, forage utilization, and dietary preferences of WTD were demonstrated in all 3 components of this study. Project limitations prevented the conclusive recommendations of the benefits of grazing tannin rich forages (Barry and McNabb 1999) but WTD preference suggests possibile benefits, but perhaps diet diversity is a more important observation thereby allowing individual animals to self balance dietary needs and forage intake. Increasing forage diversity in pasture systems will require extra understanding of intercropping and crop production to utilize such a system.

4.3. Supplementary Tannin

The third component of this study involved the evaluation of Quebracho and Spruce tannins as dietary supplements, the results of which identifies more questions than answers regarding their supplementation. WTD prefer a low amount of CT, and regulate intake of CT precisely consistent with findings in other ruminants (Clauss et al., 2003; and Robbins 1987), but this level of intake comes at a metabolic cost, reducing rate of weight gain. Deer can identify and select the most nutritional diet available which meets their nutritional requirements (this study) and therefore it seems reasonable to infer that there is some benefit associated with thier consumption. Although deer are adapted to tolerating tannins (Mehansho et al., 1987) we cannot identify a positive effect of their use and alternatively have reinforced other their negative effects, on feed intake, protein digestibility and urine indices of nutritional stress and thus recommend that future research be focused on this subject area.

Recommendations for future research in WTD based on this projects observations of high variability between deer, stresses the importance that every effort should be taken to minimize possible factors contributing to error in observations. As a minimum, no trial should be conducted that does not involve at least 5 replicates per treatment with multiple deer within treatment (i.e. 2-4 deer) held in pens and handled in methods that reduce stress as this could be a large contributing factor related to this variance.

This project has identified much valuable information regarding annual and perennial forage recommendations, foraging behavior of WTD, and their dietary preferences. It also discovered unique observations related to the tolerance of and adaptations of WTD to coping with CT supplementation.

Forage evaluations revealed that deer are very selective in their foraging preferences with all forages consumed, some more than others. Chicory, and Birdsfoot trefoil and Canola are good quality deer forages but have issues related to management and persistence. Alfalfa, Alsike Clover, Berseem Clover, Turnips, and Peas are all excellent deer forages that are both high in quality and preferred.

The study of condensed tannins supplementation in WTD revealed a preference for low amounts of Quebracho tannin which reduced deer performance likely through their negative effects on protein utilization and digestion, and dry matter intake.

This information will be used to improve recommendations on feeding and farm management practices to improve the health and efficiency of WTD production in North America. It will also be used for wildlife enthusiasts to improve wildlife plantings to increase viewing opportunities.

4.1 References

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5.0 Appendix

5.1. Suitability of Forage Peas, Argentine Canola, Turnips, and Berseem Clover for Annual Deer Forage in Alberta, Canada.

5.2 Introduction

Annual forages are commonly used in livestock production systems throughout the world and provide valuable alternatives to perennial forage. Incorporating annuals in a grazing system rapidly increases short-term pasture forage options during times when perennial forages are not available. Annuals can be utilized to provide alternative forage during perennial pasture rejuvenation, a frequent requirement due to the highly selective foraging behaviour of deer and removal of preferred forages from pasture swards. Crop and grazing management of annual forage can also be manipulated to ensure harvest or stockpiling of a high quality and high yielding forage.

While research on annual forage production and quality has been conducted for the cattle industry in western Canada, no research has assessed the suitability of annual forages for deer pasture. The objectives of this project were to evaluate the biomass, crude protein and neutral detergent fiber (NDF) concentrations, as well as deer utilization (kg ha^{-1} and %) and preference (frequency of deer grazing) for each of four annual forages, including forage peas (*Pisum sativum* L.), Argentine "Skyhawk" canola (*Brassica napus*, L.), "Samson" turnips (*Brassica rapa* var. *rapa*, L.) and Berseem clover (*Trifolium alexandrinum* Linn.).

5.3. Materials and Methods

5.3.1 Site Desciption

On 3 June, 2004, 2 paddocks, previously disced and fallowed in spring 2003, were each seeded to 2 replicate plots (0.11 - 0.28 ha each) of each of the 4 annual forage types in a randomized pattern with seeding information summarized in Table 5.1. The predominant soil type was an Orthic Gray Luvisol of the La Corey, Plamondon and Spedden series. Pen 1 was used as a test site to observe, but not quantify, general preferences of deer for different forage species, plant parts, and utilization, which was subsequently used to plan more robust sampling procedures for a later trial in the second pen.

5.3.2. Forage Quality and Yield Sampling

Forages were sampled in pen 2 on 20 June 2004 (17 days after seeding), 4 August 2004 (73 days) and 15 August 2004 (84 days after seeding) to determine seasonal changes in annual forage crude protein and neutral detergent fibre (NDF) concentrations. On 20 June, 1 composite sample of 3 randomly selected whole plants of each of the forage types was collected and analyzed for forage NDF and crude protein. On 31 July, 4 samples comprised of the flowers of 4 individual canola plants were collected as deer were selecting these plant parts heavily. As deer were previously observed in pen 1 to be very selective in their feeding patterns, plant parts were also assessed for quality on 4 August, 2004, using categories that emulate deer plant selection (Table 5.2). Sampling involved the collection of 3 or 4 randomly selected samples (each comprised of a 6-plant part composite sample) per forage type. All samples were dried at 60^0C to constant weight and ground to pass a 1-mm screen using a Wiley Mill. Forage nitrogen (N) levels of the different forages were assessed using a LECO FP-528 nitrogen auto-analyzer (AOAC 1995), with N values converted to % crude protein using a conversion index of 6.25. Neutral detergent fibre (NDF) was determined using the Ankom filter bag technique (Ankom Technology Corporation 2005).

The deer grazing trial began on 4 August, 2004 and lasted 12 days. During this trial, forage biomass availability ($kg \cdot ha^{-1}$) and utilization ($kg \cdot ha^{-1}$ and %) were measured by clipping 0.5 m x 1.0 m quadrats inside and outside each of 3 grazing exclosures (1.5 x 1.5 m) within each of the 2 plots for each forage type. Forage utilization at each exclosure was determined as the difference between grazed and ungrazed quadrats for the seeded forage and weeds within each forage type. While peas, berseem clover and canola were harvested to the plant level, the biomass of turnips was separated into turnip leaves and roots. Samples were also analyzed for sward-level crude protein and NDF concentrations.

Research procedures were approved by the University of Alberta Animal Policy and Welfare Committee according to the Canadian Council on Animal Care (CCAC) Guidelines. During the grazing trial approximately 75 deer had access to the pen. Deer were observed in 3 trial periods (Early-days 3 to 6; Mid-days 7 to 9; and Late-days 10 to 12). During daily observation periods of 75 minutes, the number of actively foraging deer in each plot and forage type were recorded 15 times at 5 minute intervals. These frequency data were then summed within each forage type across the 15, 5 minute interval scans and divided by the total number of deer observed grazing to calculate the proportion of total deer foraging within each of the 8 forage plots. For example, if 10 deer were observed feeding in pea plot 1 and observed 15 times that day, a total of 150 deer would be divided by the total number of deer observed for that day grazing in all forage plots. If 600 deer were located that day, then 150/600=0.25 or 25% estimate for this pea plot. These estimates were compared among forage types within each trial period and across the entire trial.

5.4. Data Analysis

No analysis was done on the forage quality data from before August due to the lack of replication. Forage quality data from 15 August, 2004 were analyzed with Statistical Analysis Software (SAS) systems edition 9.1 (SAS 2002). Measured response variables in this study included forage NDF, crude protein, utilization ($kg \cdot ha^{-1}$ and %), and % of deer grazing in each forage type. All data were analyzed using an analysis of variance (ANOVA) with Proc Mixed (SAS 2002), where seeded forage type was a fixed factor. Where significant main effects or interactions were found ($p<0.05$), post-hoc comparisons of lsmeans were performed using the pdiff method (SAS 2002), with differences considered significant at $p<0.05$, unless otherwise indicated.

5.5. Results

5.5.1. Forage Quality Assessment

In paddock 1, deer were highly selective in their foraging, both among seeded forages, and within each forage plant. Peas, berseem clover, turnips, and canola, and a preferred weed species, lambsquarters (*Chenopodium album* L.), were sampled to provide an initial evaluation of forage quality on 20 June, 2004. Crude protein concentrations at this early date ranged from 17 to 30% among forages (Table 5.3), and were greatest in turnips and lowest in berseem clover. NDF concentrations at this time ranged from 24 to 51% and were lowest in the turnip plants, intermediate in peas, and greatest in canola and clover.

Sampling of plant parts on 4 August, 2004, emulating deer forage selectivity in pen 1, suggested deer foraging behaviour allowed them to select higher levels of crude protein (Figure 5.1) and lower NDF (Figure 5.2), translating to the highest quality forage available. Forage crude protein was particularly high in canola flowers and the uppermost leaves, tendrils and flowers of peas at this time both averaging approximately 30%, as much as 22% greater than berseem stems. Additionally, NDF concentrations were lowest in both of these plant parts at this time.

Sampling within paddock 2 on 15 August, 2004, the final day of the grazing trial, identified a significant effect of forage type on biomass ($p=0.0003$), with biomass greatest in canola (11 196 $kg \cdot ha^{-1}$) and second highest in the whole turnip plant (Table 4.4). In contrast, peas and Berseem clover produced the least biomass, and were also associated with a high abundance of weeds (Table 5.4) Concentrations of NDF were affected by forage type ($p<0.001$), being greatest in the canola plant (52.0%), intermediate in Berseem clover and peas, and particularly low in turnips (Table 5.4). In contrast, whole plant crude protein levels were similar ($p>0.05$) among forage types in August, ranging from 14 to 14.7%.

Turnip plants had a large difference in above and below ground biomass and as such, comparisons in forage agronomic traits were made on leaf and root material. Turnip biomass was effected by Turnip plant part ($p=0.02$) (Table 5.4) with leaf material producing (5959 $kg\cdot ha^{-1}$) 183 % of its root biomass. The crude protein and NDF concentration of turnip tubers and leaves were similar within the turnip plant (p=0.06) (p=0.21) respectively despite moderate differences of 7% for both NDF and crude protein. Turnip roots had the lowest NDF concentrations of all of the other whole plant forages (22.4%).

5.5.2. Deer Utilization and Foraging Preference

Utilization ($kg\cdot ha^{-1}$) of forages was not affected by forage type (p=0.67) and it was highest in berseem clover (2935 $kg\cdot ha^{-1}$) and lowest in peas (1873 $kg\cdot ha^{-1}$) (Table 5.4). Proportional utilization (%) was affected by forage type (p=0.03), being greatest in berseem clover (66.4%) and lowest within canola (20.7%). Utilization (%) within the turnip forage type was not affected by plant part (p=0.07) despite a difference of 14% in utilization (Table 5.4). Utilization ($kg\cdot ha^{-1}$) within the turnip plant was effected by turnip plant part (p=0.03) with deer consuming (1383 $kg\cdot ha^{-1}$) more leaf biomass than root biomass.

Weed biomass was considerable within the pea and berseem forage types and not present in the canola and turnip forage types. Weed biomass was not affected by forage type with weeds in the pea forage type producing 4652 $kg\cdot ha^{-1}$and berseem weeds 2026 $kg\cdot ha^{-1}$. Utilization of weeds within the pea and berseem forage types (% and $kg\cdot ha^{-1}$) did not differ (p=0.64 and p=0.21) respectively.

Forage type had a significant effect on where deer preferred to graze in paddock 2 both during the entire trial (p<0.0001) and within each trial period (p<0.001). Across the whole trial, deer preferred to graze berseem clover (42.8%), followed by peas, turnips and canola (6.5%) (Table 5.5). Among specific trial periods the pattern of preference remained high for berseem and low in canola, with preference for peas and turnips varying. Pea preference was equal to berseem clover until the last period of the trial, at which time preference for this forage type sharply declined coincident with reduced biomass as a result of high utilization. In contrast, preference for turnip increased to 29.9%, suggesting deer switched from peas to turnips at this time (Table 5.4).

5.6. Discussion

5.6.1. Forage Evaluation

The use of annual forages to complement perennial pastures for deer grazing was evaluated in the 2004 growing season. Preliminary observations of deer forage selection indicated that deer preferred canola flowers and the upper leaves, flowers, tendrils and pods of peas at the beginning of grazing in each pen. These plant parts were rapidly depleted as they represented relatively little biomass. Once these two high quality feed sources were eliminated as a forage choice, deer switched to a preferential pattern more indicative of that evident in the utilization and preference results. This demonstrates the supported notion that deer are highly capable of identifying and selecting the best quality plants and plant parts available.

This ability was reaffirmed in the deer forage preference study where deer preferred the peas and berseem clover forage types overall. Low NDF concentrations partially explain why deer preferred these forages. A possible reason for deer not preferring turnips is the presence of a moderate to strong astringent flavour when ingesting the turnips. This lack of preference for turnips was identified in the early preliminary pen 1 trial and I decided to personally sample all plants and plant parts to see what they tasted like. My taste testing revealed, that of all the forage types in Table 5.1, that the turnips had a very peppery or radish like, spicy, astringent flavour, the degree of which declined as the season progressed from mid-July to the end of testing in mid-September.

Deer also appeared to take some time to learn that turnip bulbs were available as this was not like any other forage option available to them in previous grazing history. Deer first consumed turnip leaves and then, in areas where leaves had been removed and the tubers exposed, began to lightly chew on tubers. Occasionally deer would pull the tuber out of the ground only to eat the leaves and drop the turnip on the ground as they appeared to struggle with apprehension of the tuber given their shape and size. Tuber sizes of the turnip ranged from 5-12 cm in diameter. By the late period of the trial deer apprehension of the bulb had improved. Although turnips were only utilized at 24.7% by the end of the formal grazing trial, by spring 2005, an ocular estimate of the study area revealed less than 5 % of the leaves and tubers remained. All turnip tubers had been pawed up and eaten or chewed to deer muzzle depth. Another possible reason for this increase in turnip preference could be that the complex polysaccharides in the turnip begin to break down into more simple sugars late in the fall and especially after a frost, changing the flavour of the turnip to a sweeter taste, improving palatability. Furthermore, forage preferences are known to increase with exposure to a forage item.

Canola use by deer was particularly low of all the forage types and plant phenological stage at the time of the grazing trial in pen 2 likely favoured the other forages. After full bloom, approximately 5-10 days prior to the start of the grazing trial, canola had started to grow pods, set seed, switching from vegetative to reproductive growth, followed by initiation of the ripening process causing a change in preference. Casual observations in late July in pen 1 recorded deer utilizing much of the upper half of the plant at this time. NDF levels, although not measured, clearly increased sharply with plant ripening with much of the canola biomass wasted as the leaves began to dry up and fall to the ground, with the stems being almost completely avoided. Assuming deer utilization of canola is greater in early stages of growth, it could provide the greatest amount of palatable biomass as compared with the other 3 forages.

Canola produced the most biomass of all forages but lacked preference as perhaps management (i.e. Early vs. late quality-seeding date) reduced its suitability as deer forage. Peas and berseem were both high yielding and high quality and supports other research in western Canada (Frazer et al., 2004; Ross et al., 2005). Turnip and canola biomass and were over double in this study as compared to another study (Phelps et al., 2003) and our results that they were both greater than berseem and peas is supported in the literature (Fraser et al., 2004). Other brassica's that are high yielding and may be alternative forages in western Canada are available (Rape *(Brassica napus* L) and Kale (*Brassica oleracea* convar. *Acephal*).

Weed growth was high in the pea and berseem clover forage types indicating a lack of weed competitiveness which was attributed in berseem to competition for light (Ross et al., 2005). Aggressive growth and leaf area in the turnip and canola forage types is likely why these crops were so competitive. Another possible reason for the increased weed biomass in the berseem clover and pea forage types is that these forages are leguminous (Ross et al., 2001), and fix nitrogen in the soil, increasing the nutrients available for weed growth and quality of weeds. Deer were observed selecting much weed plant material in the berseem forage and pea forage type, yet this is not evidenced in the biomass data. A possible reason for this under estimation is that these estimates are gravimetric. The leaf material of the weeds does not weigh much and was highly used and was low in fiber relative to the stems (unmeasured), which they tended to avoid. Thus, although nutrient yield from weed leaves may have been high, gravimetric assessment of utilization may have been underestimated.

5.6.2. Annual Forage Grazing Considerations

These annual forages all show potential for use as deer pasture forage however the following is a discussion of some of the considerations that may improve their use.

The high utilization (%) of turnips combined with its high biomass and quality, results in turnips having the greatest nutrient yield of all forages tested. Turnips could prove to be the best annual forage available as the leaves can be grazed once in the summer at peak biomass, occurring between 53-60 days after seeding, and then the leaf and root regrowth can be grazed again in late fall (See Phelps et al., 2003 for a good central Saskatchewan quality and variety trial). Turnips are also very frost resistant (-5°C) (Phelps 2003) and provide excellent quality forage especially valuable in late fall when forage quality is much higher than many alternatives. Any turnips that are not consumed prior to freeze can be cleaned up in early spring. Lower than expected rates of gain in brassica are often attributed to high forage water content and inadequate fiber intake for ruminal function (Lambert et al., 1987), or anti-quality compounds that result in health concerns including thyroid dysfunction and anemia (Smith, 1980).

Peas can provide good biomass in a 1 or 2 cut system (cut late July and mid September) (5100 kg·ha^{-1}) (Fraser et al., 2004) with yields averaging slightly more biomass than our study across central Saskatchewan and southern Alberta (Fraser et al., 2004- this study is an excellent reference for annual forage evaluations across Saskatchewan and Alberta including peas and berseem clover and several other annual forages). In a one cut system preference for peas would likely decline with increased NDF concentrations when the crop begins to ripen. Grazing is therefore recommended at approximately time of full bloom to pod formation (75 days after seeding in this study). Trampling of pea biomass may become an issue at lower stocking rates as this was noted in our study. Peas are good candidates for intercropping systems as they are leguminous with much research on this subject (see list of suggested readings for more information).

Berseem clover is highly preferred deer forage but it may be better suited to more southern regions of Alberta as average yields were greater across central Alberta and Saskatchewan (6600-7400 kg·ha^{-1}) (Fraser et al., 2004; Ross et al., 2005). Growth rate of berseem is slower early in the season with growth increasing sharply 55 days after planting to 2.5 times greater than that of earlier growth. It also has the added benefit of maintaining forage quality late into the season with regrowth in fall averaging 21% CP (Ross et al., 2005). Berseem clover crude protein declines from 31-18% between 35-88 days after planting (Ross et al., 2005).

Peas and berseem clover in this study are less competitive with weeds and are leguminous making them more suitable as intercropping species (Berseem-Ross et al. 2001, 2004, 2005). Berseem is not a good competitor and should only be grown with non-competitive cereals, like that of triticale where regrowth of a mid-summer cut was found to contain proportionally more berseem clover than that of the cereal (Ross et al., 2004, 2005). This system would provide good mid summer grazing, late fall regrowth grazing, and then excellent early spring grazing if grown with a winter cereal (fall rye, winter wheat, and winter triticale).

Canola use declines sharply following full bloom and pod development. Timing of grazing, to maximize nutrient yield, should be planned so that it starts prior to full bloom which occurred approximately 63 days post seeding in this study. Seeding date could be delayed to time forage growth with expected forage demands. Seeding in mid-summer, timed with date of average frost, could be used as an extensive management option to desiccate the crop, stopping forage growth, but may require forage quality analysis to assess risk of nitrate toxicity. Swathing the forage stand prior to frost may be a good method to stop growth and also prevent wastage due to trampling or should snowfall prevent grazing earlier than expected

Rejuvenation of perennial pastures could be accomplished by seeding in the fall by mechanical means or by hoof action during grazing, or in the spring by frost or mechanically seeding. A rest period of 1 or 2 years between perennial stands, during which time annuals were grown, may be a suitable option for many deer farmers to provide valuable grazing during this periods.

These research results not only benefit deer producers, but also anyone interested in increasing the forage quality and availability for wild deer to improve wildlife watching or hunting opportunities.

5.7. Conclusions

1. Deer exhibit a highly selective foraging behaviour that is very sensitive to forage quality and should be a primary consideration in developing any grazing plan.
2. Turnips, Berseem clover, and peas, are excellent annual deer pasture forages and while canola is good in quality its careful management is needed to improve utilization.

3. Peas and berseem clover offer advantageous agronomic traits for the use inter-cropping systems with winter cereals.

4. Inclusion of these forages into a grazing system should involve careful planning and crop management to insure they are suitable forages for your needs and to ensure that forage quality and yield are timed with forage demand.

5. Further research is needed on performance parameters of deer grazing these annual forages to assess whether there are any feeding concerns that may become an issue under longer-term grazing trials. Research should also be focused on changes in nutrient yield and palatability of these forages throughout the growing season and how these affect the economics of their use as deer pasture.

5.8. Suggested References for More Information

1. **Agricultural Research and Extension Council of Alberta**

   http://www.areca.ab.ca/

2. **Alberta Agriculture: Ropin the Web Website**

   http://www.ropintheweb.com

   2.a. Annual Crops for Grazing

   http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop8062

   2.b. Forage brassicas

   http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex135

3. **Alberta Pulse Growers Association**

   http://www.pulse.ab.ca/

4. **Fraser, J., McCartney, D., Najda, H. and Mir, Z. 2004.** Yield potential and forage quality of annual forage legumes in southern Alberta and northeast Saskatchewan. Can. J. Plant Sci. 84: 143–155.

5. **Grazing and Pasture Technology Program**. 1999. Pasture and forage for White-tailed deer. Box 4752, Regina, Saskatchewan, S4P 3Y4

6. **Local Farmers in your area**:

   Can provide useful information on local cropping systems.

7. **Manitoba Forage Council**

   http://www.mbforagecouncil.mb.ca/default.aspx

8. **Saskatchewan Agriculture and Food**

   http://www.agr.gov.sk.ca/document_level_3.asp?cat=6&cat2=39&cat3=72
   Contains many manuals available for download on topics such as annual crops for pasture, grazing, swath grazing silage, and pasture forage for elk and much more.

9. **Saskatchewan Forage Guide 2007**

   http://www.agr.gov.sk.ca/docs/production/forageguide.asp

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5.10. Tables

Table 5.1. Seeding information summary in annual forages trial.

Forage	**Berseem Clover**	**Argentine-'Skyhawk' Canola**	**'Samson' Turnips**	**Forage Peas**
Seeding Rate ($kg \cdot ha^{-1}$)	10.9-16.5	11	7.6	6 (bushels $\cdot ha^{-1}$)
Coating	n/a	Blue Coat and Helix Fungicide and Insecticide	Redcoat phosphate	n/a
Supplier	Pickseed	Prairie Seeds	Prairie Seeds	Galloway Seed Farm
Cost $/kg	4.50	5.90	6.00	0.417
Cost $/ha	54	65	46	60
Germination	85%	95 %	n/a	n/a

Table 5.2. Emmulated plant part selection categories and sample sizes, 4 August, 2004.

Forage Type	**Plant Categories**	**n**
Berseem Clover	Leaves	3
	Stems	3
Canola	Flowers	4
	Flowers and Pods	4
	Stems	4
	Leaves	4
Turnip	Tubers	4
	Leaf Stems	4
	Leaves	4
Pea	Stems	3
	Lower Leaves	3
	Uppermost 10cm Leaves, Flowers, & Tendrils	3

Table 5.3. Forage neutral detergent fibre (NDF) and protein concentration of annual forages as sampled 17 days post seeding on 20 June, 2004.

Forage	n	NDF	Protein
		----(%)--	----(%)---
Pea Plant	1	42.8	21.4
Turnip Plant	1	24.6	30.5
Canola Plant	1	51.7	23.2
Berseem Plant	1	50.9	17.6
Lambsquarters (preferred weed)	1	46.9	14.3

Table 5.4. Annual forage, ANOVA comparisons of neutral detergent fiber (NDF) and protein concentrations (%), biomass and forage utilization by white-tailed deer (kg·ha^{-1} and %), measured 15 August, 2004.

	NDF	Protein	Biomass	Utilization	Utilization
	-----%----	----%----	-(kg·ha^{-1})-	----%----	----(kg·ha^{-1})---
n	2	2	2	2	2
Forage Type					
P value	**0.0005**	0.96	**0.003**	**0.03**	0.67
Canola	[z] 52.0a	14.7	11196a	20.7b	2435
Berseem Clover	47.0ab	14.3	4368b	66.4a	2935
Peas	43.7a	14.2	3001b	41.8ab	1873
Turnip Whole	26.0c	14.0	9208a	22.5b	2270
SE	1.5	0.9	663	7.3	586
Turnip Part					
P >F	0.21	0.06	**0.02**	0.07	**0.03**
Turnip leaf	29.7	17.3	5959a	29.6	1777a
Turnip root	22.4	10.6	3250b	15.5	494b
SE	0.21	0.06	274	2.9	165
Weeds					
P>F	n/a	n/a	0.09	0.64	0.21
Weeds in Berseem	n/a	n/a	2026	-5.9	244
Weeds in Pea	n/a	n/a	4652	12.2	1607
SE			599	23.3	546

[z] within a row, columns with different letters are significant ($p<0.05$).

Table 5.5. Analysis of variance comparisons of the proportion (%) of total deer grazing (lsmean) within peas, canola, turnips, and berseem clover plots during the whole trial and individual trial periods between August 3-15, 2004.

Days	Forage Type	Berseem	Peas	Turnips	Canola	SE
Whole Trial						
P>F	**<0.0001**					
1 – 12	Whole [z]	42.8 a	32.3 ab	18.5 bc	6.5 c	5.4
Within trial periods						
P>F	**<0.001**					
1 - 4	Early [z]	42.0 a	45.5 a	10.6 b	2.0 b	8.3
5 - 7	Mid	38.4 a	37.2 ab	17.6 bc	6.8 c	9.6
8 – 12	Late	48.2 a	9.7 b	29.9 ab	12.3 b	9.6

[z] within a row, columns with different letters are significant ($p<0.05$)

Table 5.6. Nutritional requirements of white-tailed deer (Adapted from Feist, 1998).

Age	Month	Protein	TDN	Calcium	Phosphorous
Fawns andYearlings					
4-6 months	SeptNov	18-20%	68%	0.60%	0.30%
7-11 months	Dec-Apr	12-14%	60-62%	0.58%	0.30%
12-18 months	MayNov	12-14%	63-65%	0.50%	0.30%
Does					
Gestation	Jan-Apr	12-14%	57%	0.50%	0.40%
Late Gestation	Apr-May	14-16%	59%	0.50%	0.40%
Lactation	June-July 15	14-16%	64%	0.70%	0.40%
Lactation	July 15-Aug	12-14%	61%	0.60%	0.40%
Pre rut	Sept-Oct	10-12%	61%	0.50%	0.40%
Maintenance	Nov-Dec	7-10%	51%	0.35%	0.25%
Bucks					
Maintenance	Jan-March	7-10%	51%	0.35%	0.25%
Antler Growth	Apr-Aug	16%	55%	1.40%	0.70%
Pre Rut and Rut	Sept Dec	12-14%	60%	0.50%	0.40%

5.11. Figures

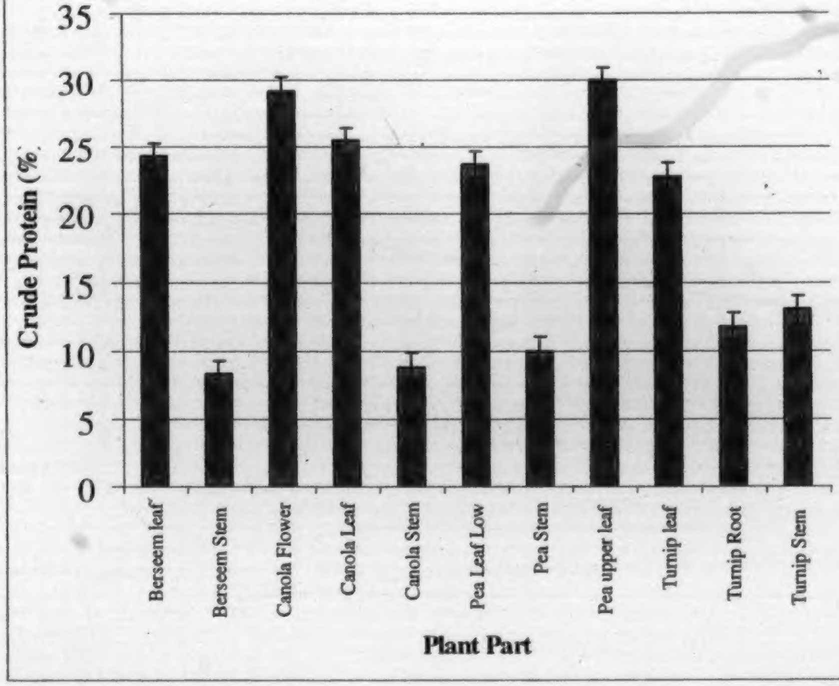

Figure 5.1. Crude protein concentration (%) in annual plant parts sampled 4 August, 2004.

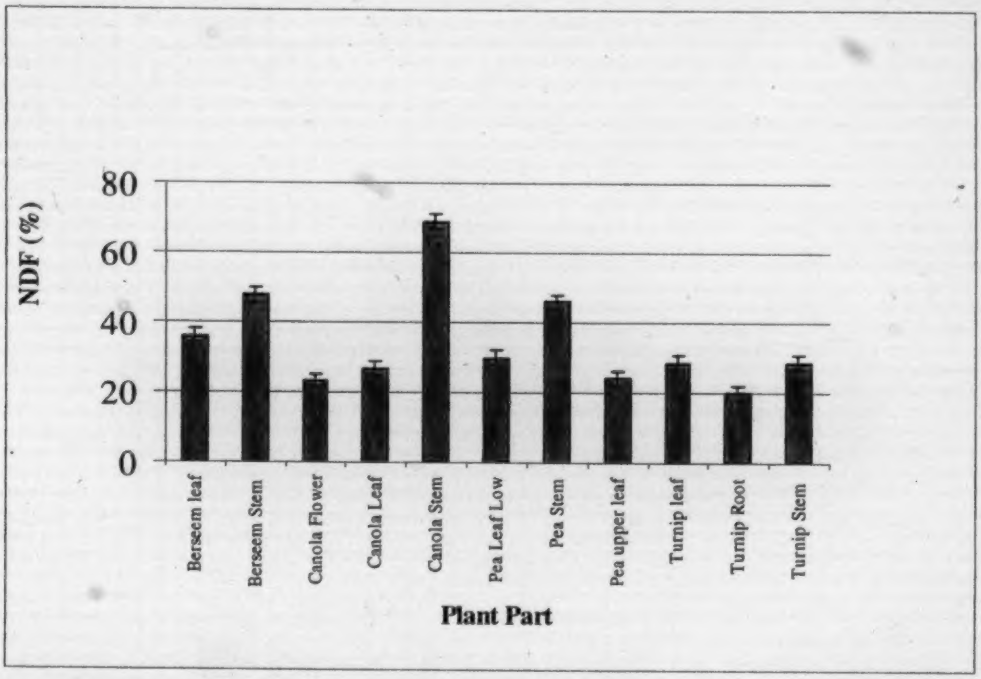

Figure 5.2. Neutral detergent fibre (NDF) concentration (%) in annual forages plant parts sampled 4 August, 2004